IFDS Framework

CMPUT 620 — Static Program Analysis

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GSB 8-59

Interprocedural Finite Distributive Subset Problems

Thomas Reps, Susan Horwitz, and Mooly Sagiv. Precise Interprocedural Dataflow Analysis via Graph Reachability. ACM SIGPLAN-SIGACT Symposium on Principles of Programming Languages (POPL ’95), pages 49–61.

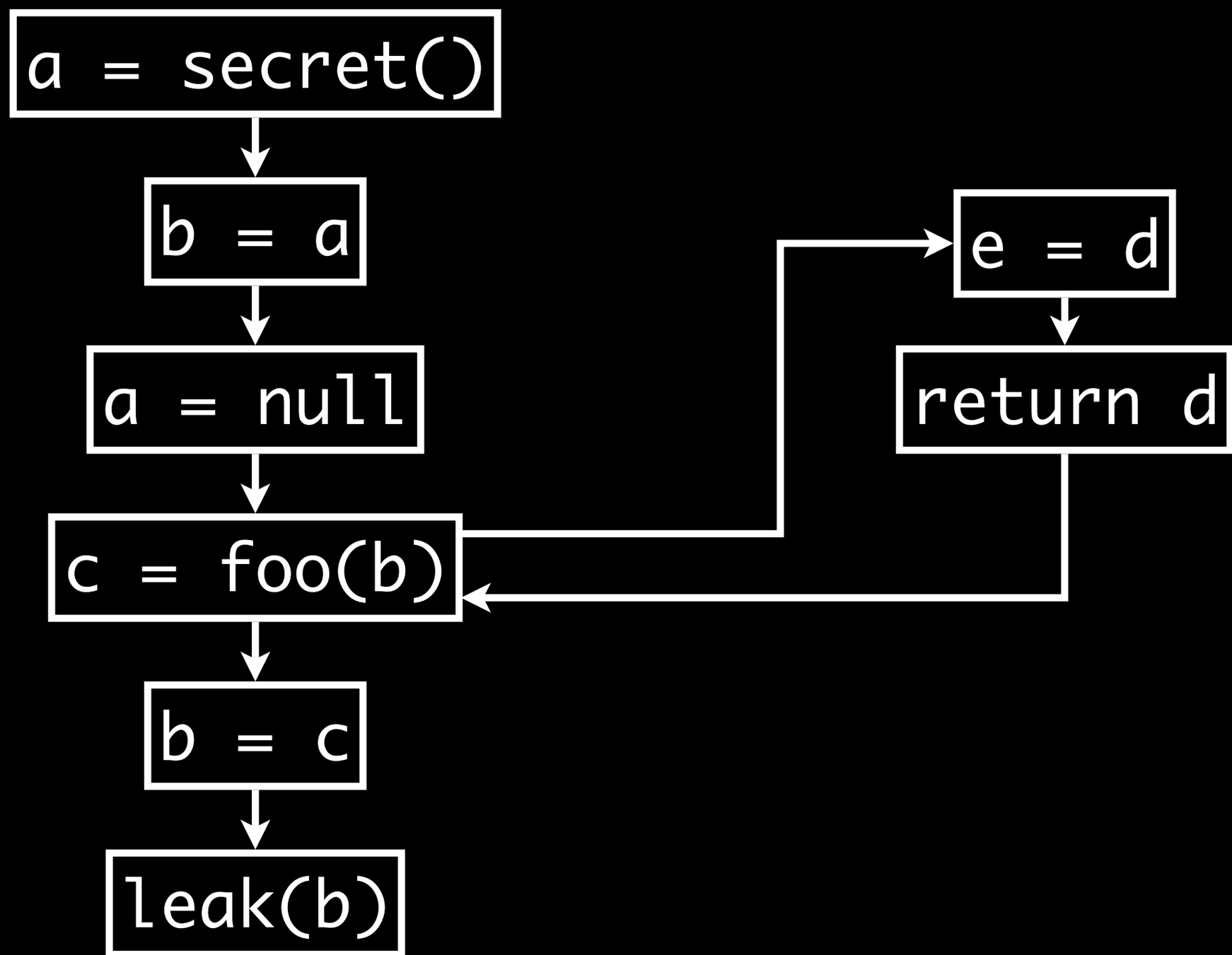
Interprocedural **F**inite **D**istributive **S**ubset Problems

Interprocedural

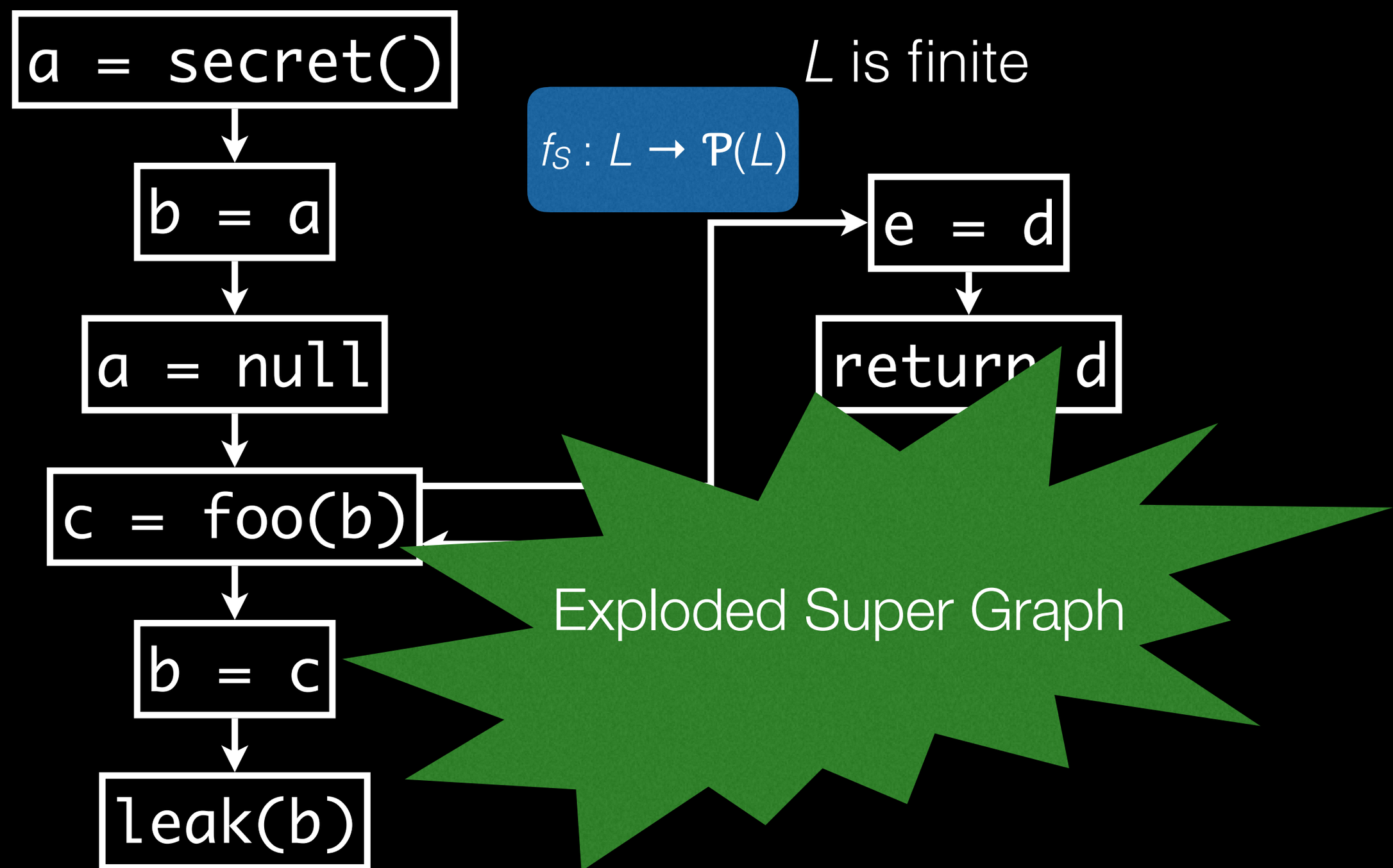
```
main() {
  a = secret();
  b = a;
  a = null;
  c = foo(b);
  b = c;
  leak(b);
}
```

```
foo(d) {
  e = d;
  return d;
}
```

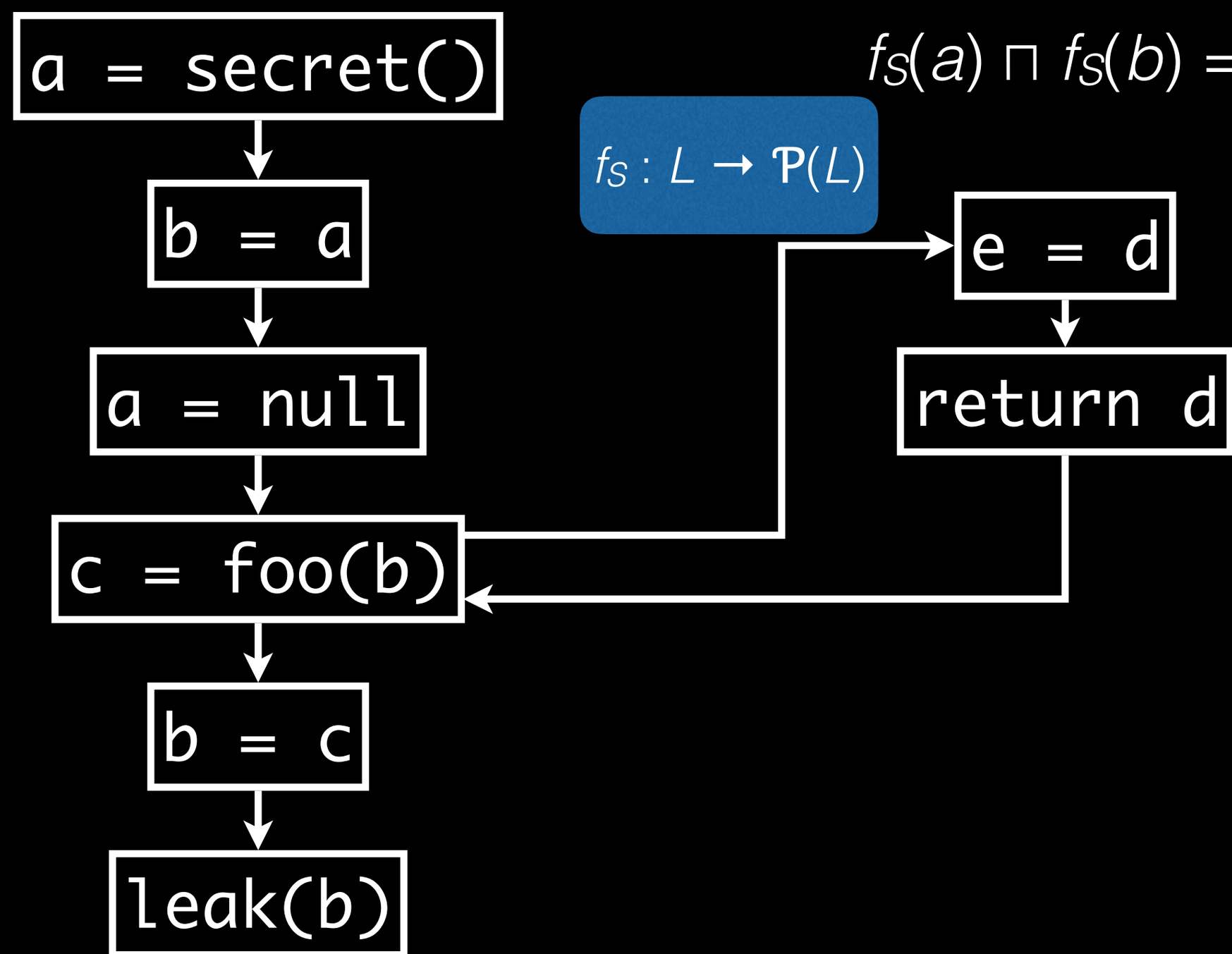
Interprocedural



Finite


a = secret()
b = a
a = null
c = foo(b)
b = c
leak(b)
L is finite
$f_S : L \rightarrow \mathcal{P}(L)$
e = d
return d
Exploded Super Graph

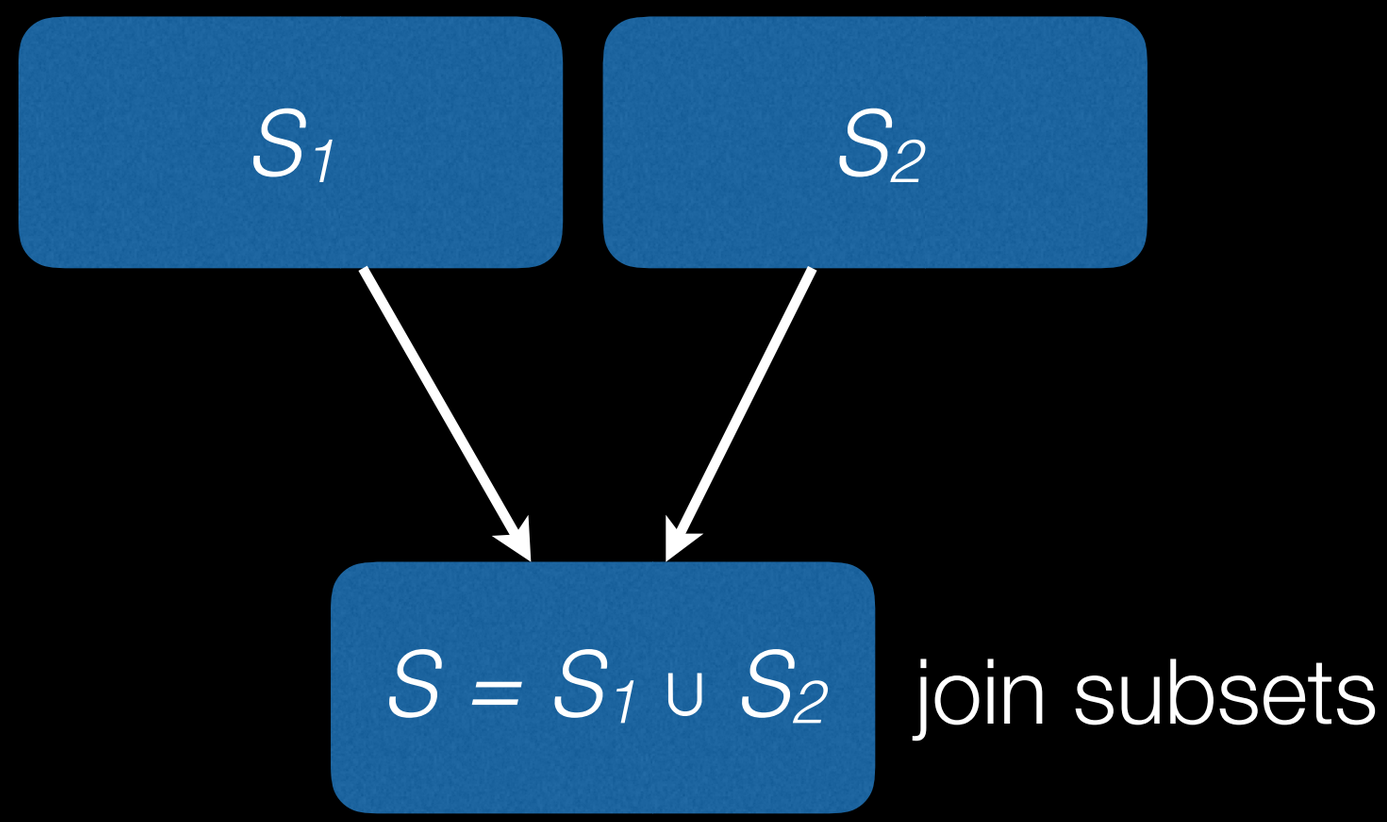
Distributive



$f_S(a) \sqcap f_S(b) = f_S(a \sqcap b)$

$f_S : L \rightarrow \mathcal{P}(L)$

Subset



alias

taint

typestate

IFDS

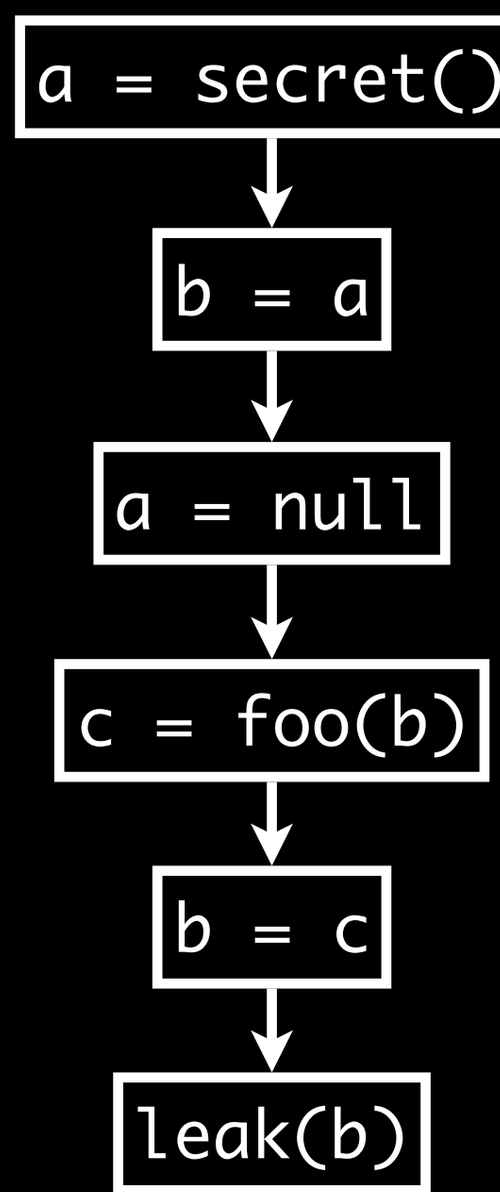
constant propagation

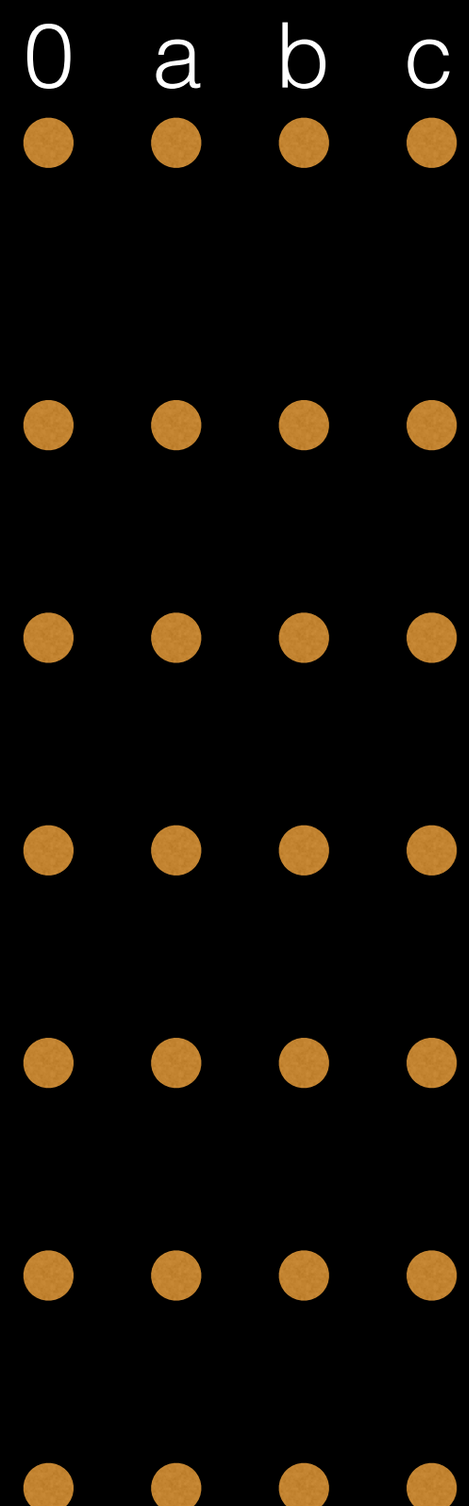
reaching definitions

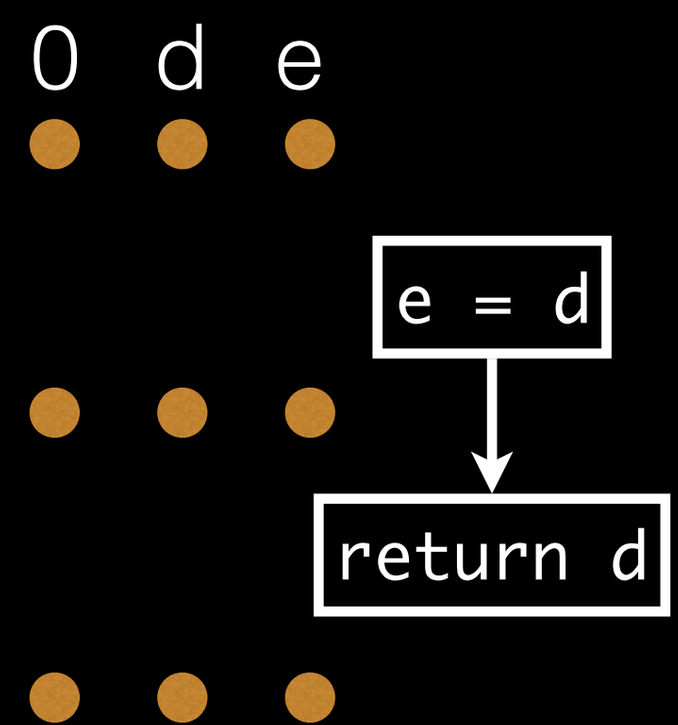
uninitialized variables

Graph Reachability

Graph Reachability





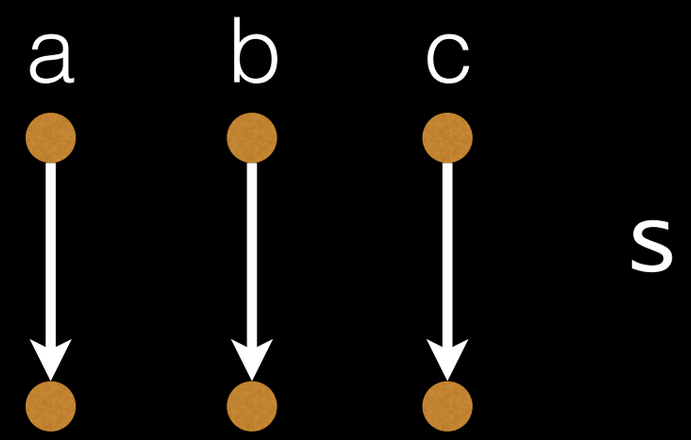


- each node is a fact
- fact holds at a statement => node is reachable in ESG

Examples of Flow Functions

Identity Flow Functions

in(**s**) = facts before **s**

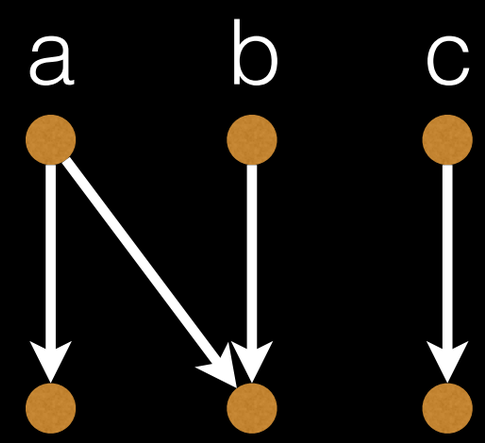


out(**s**) = facts after **s**

every fact is reachable iff it was previously reachable

Flow Functions

$$\text{out}(\mathbf{s}) = \begin{cases} \text{in}(\mathbf{s}) \cup \{b\} \text{ if } f \in \text{in}(\mathbf{s}) \\ \text{in}(\mathbf{s}), \textit{ otherwise} \end{cases}$$



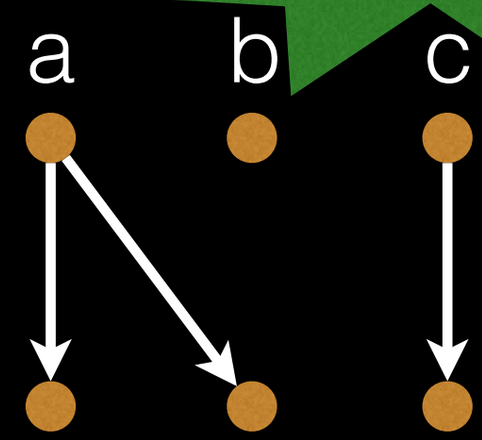

```
s: b = a
```

every fact is reachable iff it was previously reachable, and *b* is also reachable if *a* was reachable

Flow Functions

Taint Analysis

$$\text{out}(\mathbf{s}) = \begin{cases} \text{in}(\mathbf{s}) \cup \{b\} \text{ if } f \in \text{in}(\mathbf{s}) \\ \text{in}(\mathbf{s}) \setminus \{b\}, \textit{ otherwise} \end{cases}$$

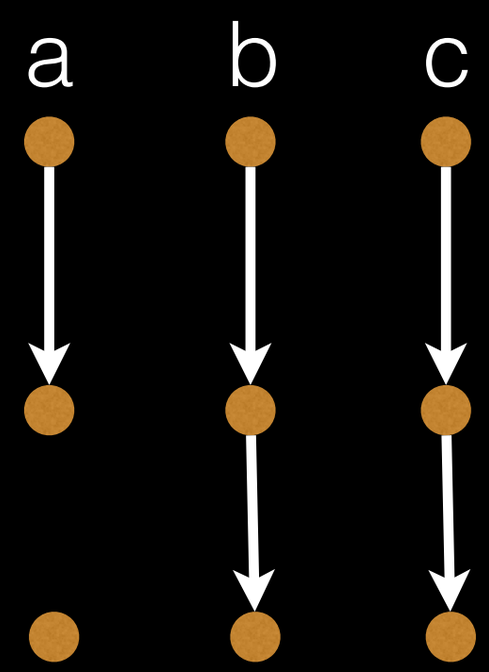



```
s: b = a
```

every fact except *b* is reachable iff it was previously reachable; *b* is reachable if *a* was reachable

“Killing” Facts

out(s) = in(s) \ {*a*}




```
a = secret()
```

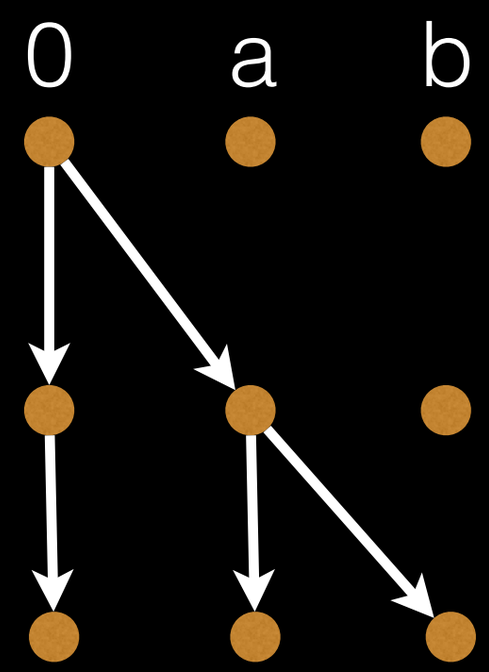
```
s: a = null
```

a is not reachable, even if it was before

Generating Facts

out(**s**) = in(**s**) ∪ {*a*}

out(**s**) = in(**s**) ∪ {*b*}




```
a = secret()
```

b = a

0 is the tautological fact => always reachable

Non-Distributive Flow Functions

e.g., full constant propagation

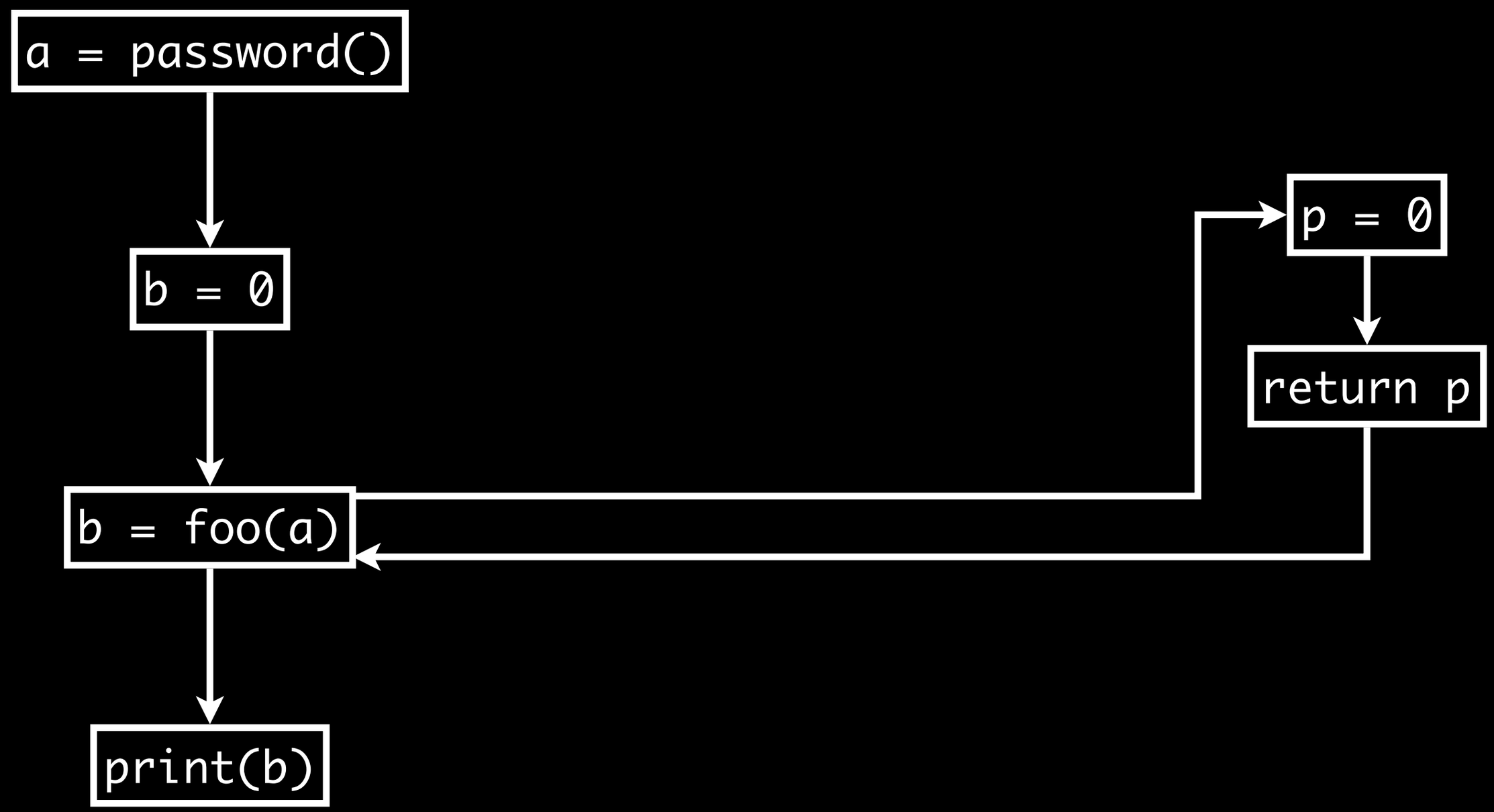
c = a + b

Taint Analysis Example

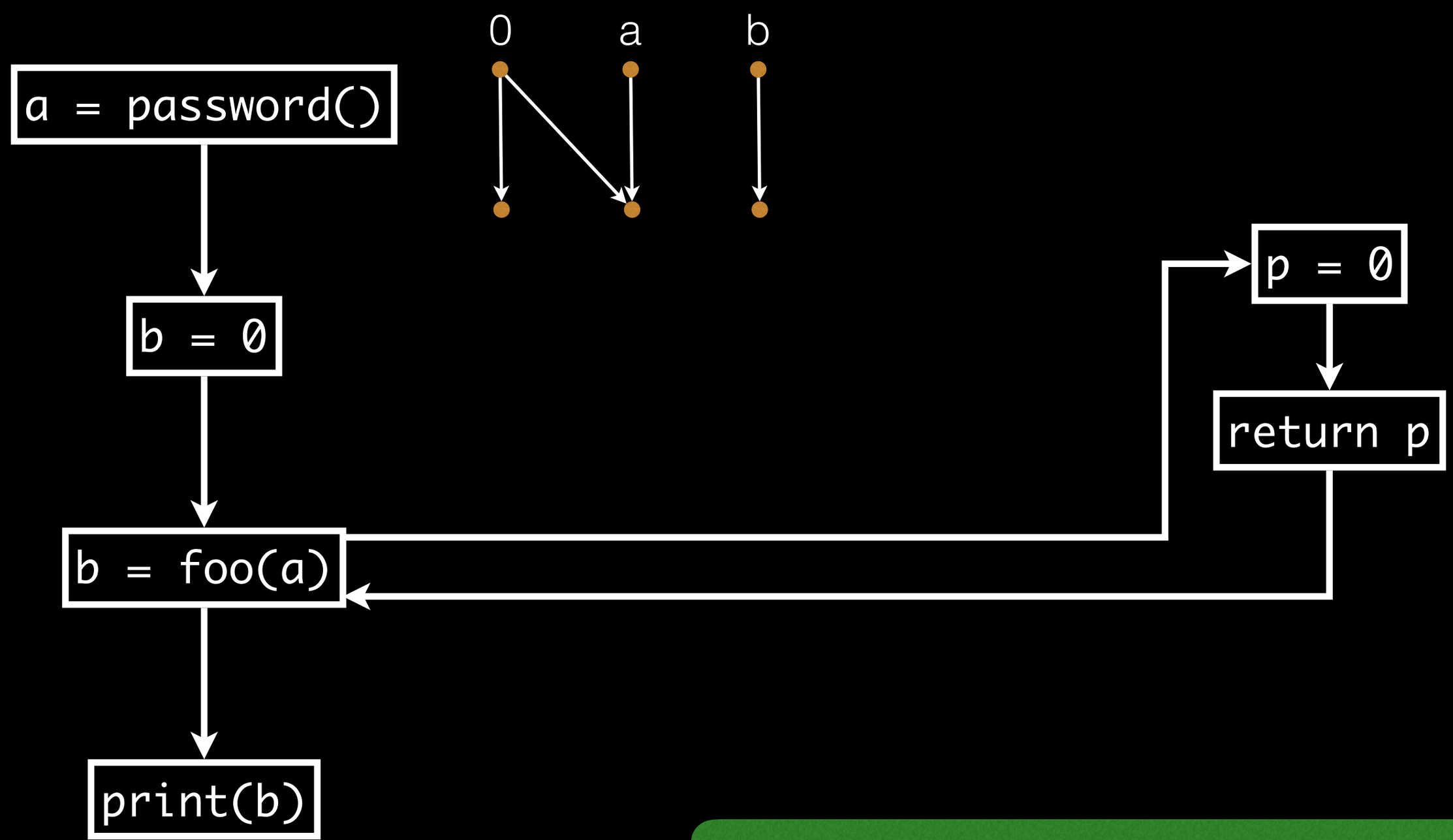
```
void main() {
    int a = password();
    int b = 0;

    b = foo(a);

    print(b);
}
```

```
int foo(int p) {
    p = 0;

    return p;
}
```

Taint Analysis Example

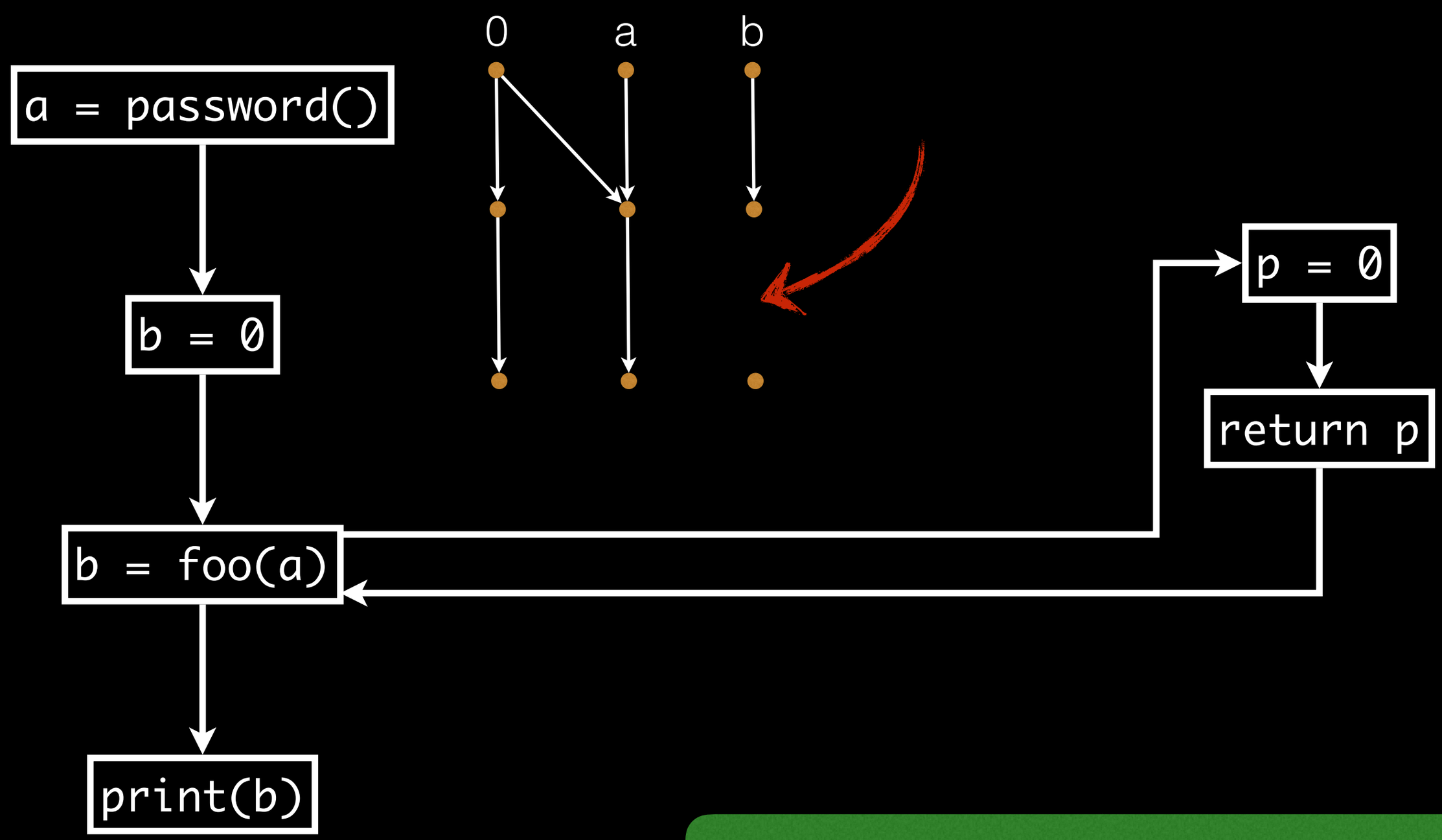


Taint Analysis Example



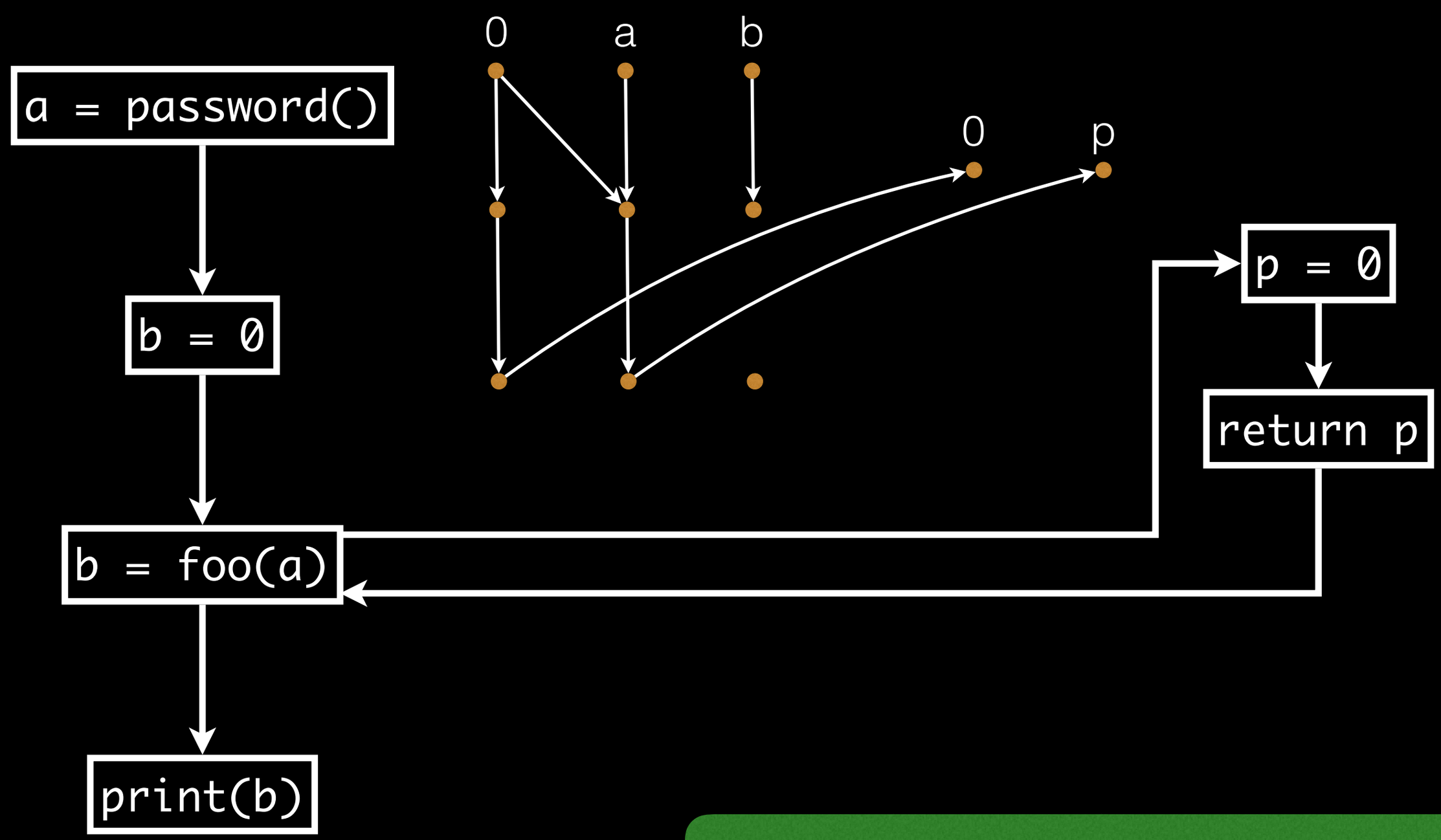
Normal-Flow Function

Taint Analysis Example



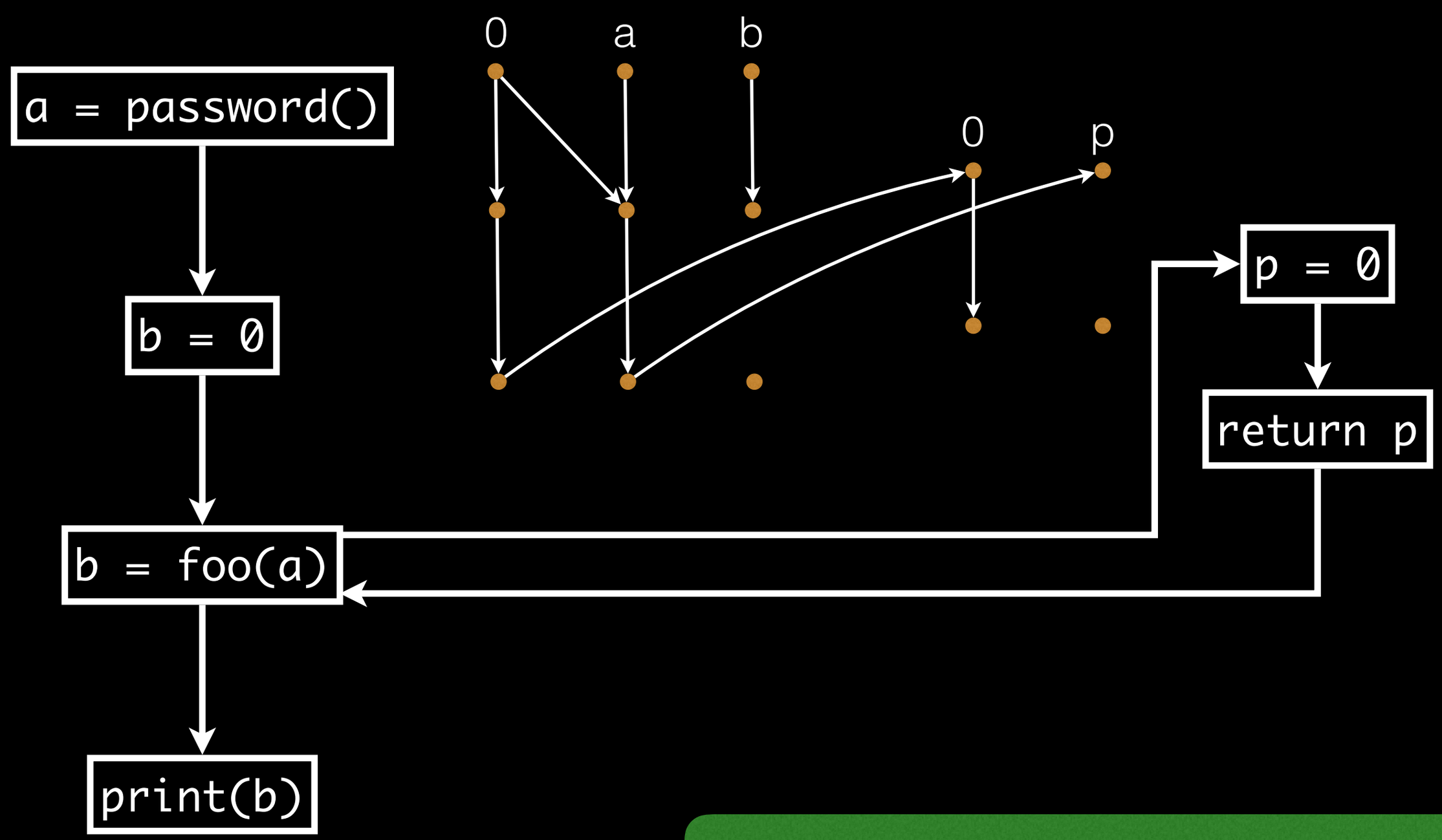
still Normal-Flow Function

Taint Analysis Example



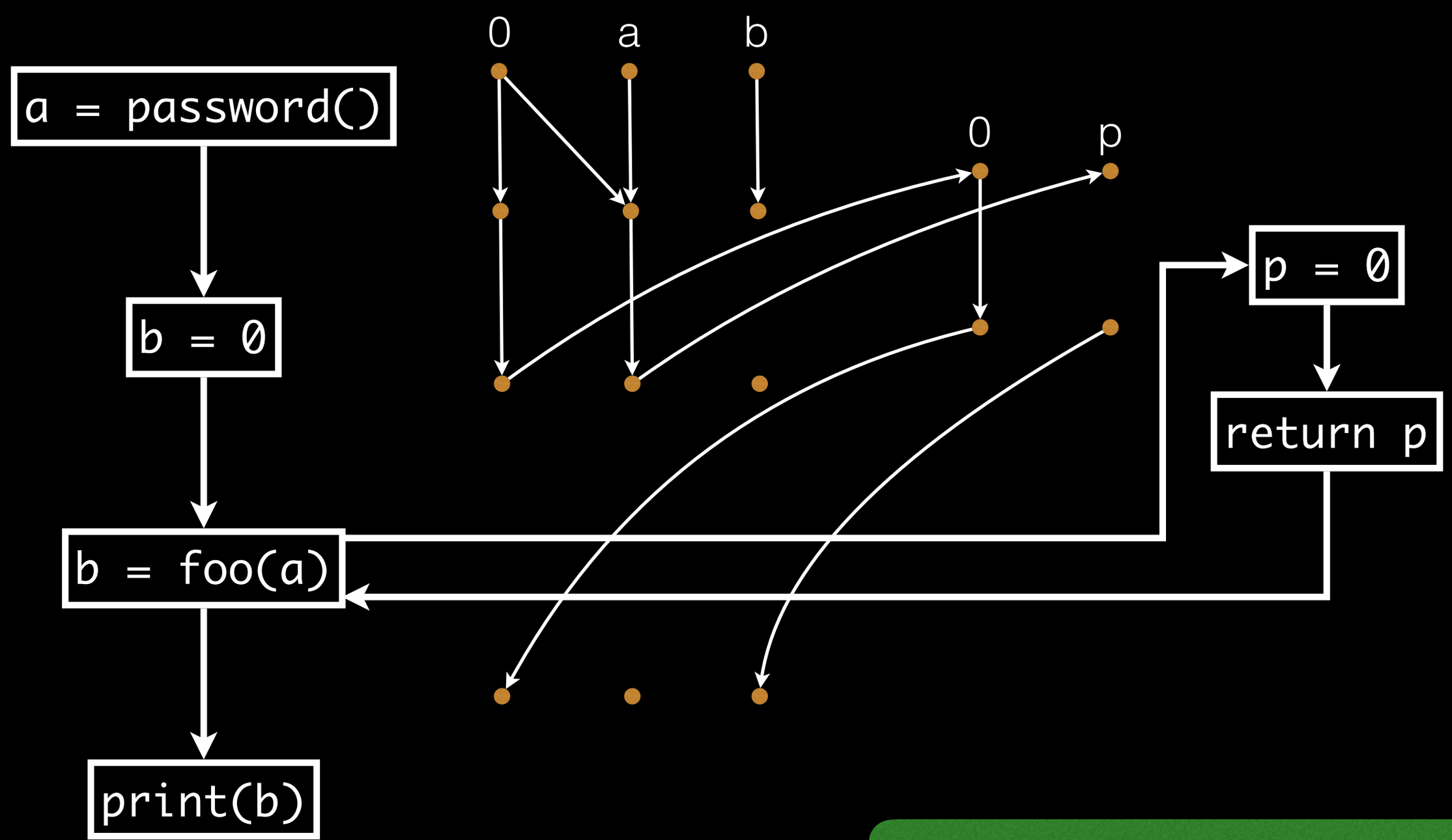
Call-Flow Function

Taint Analysis Example



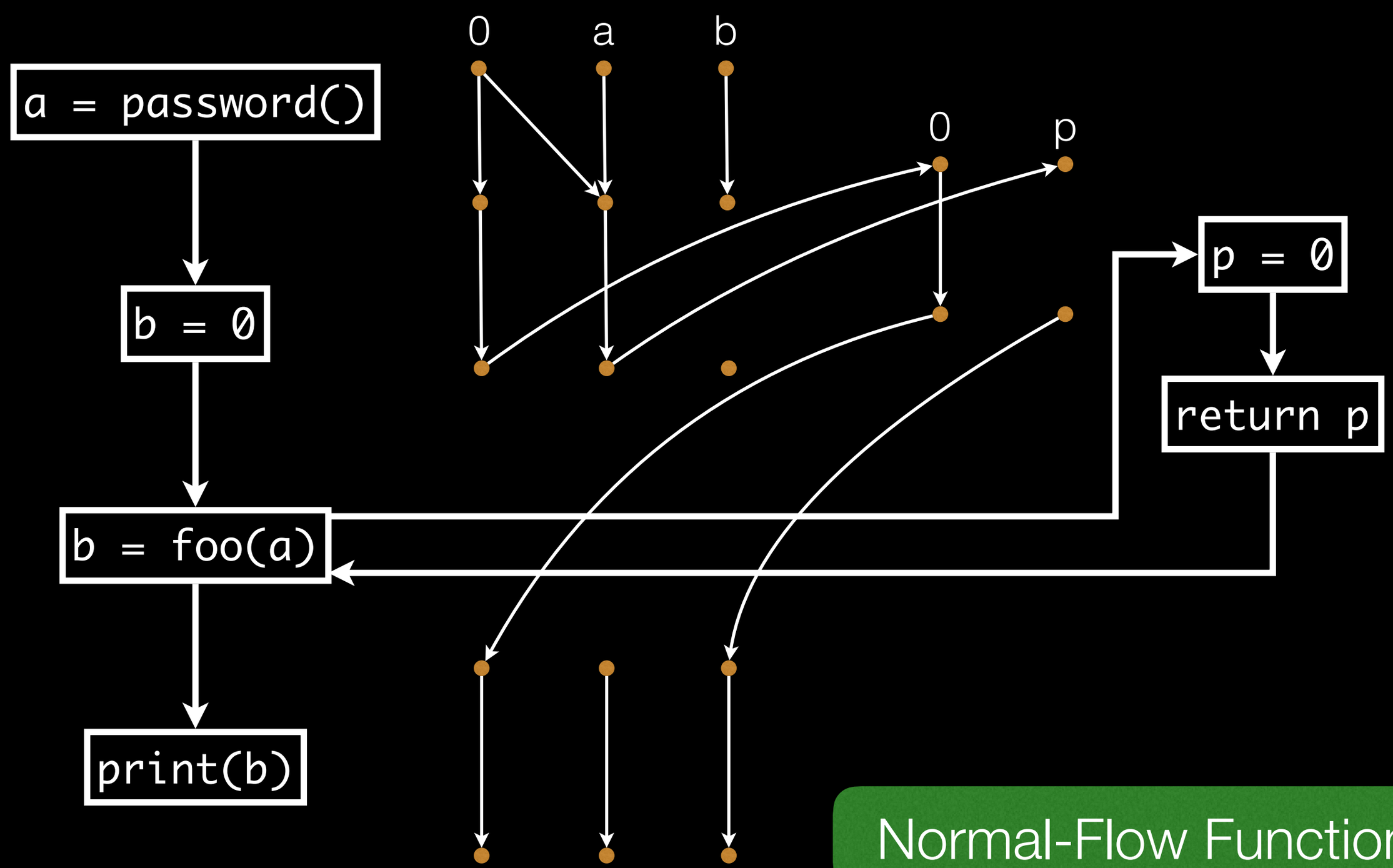
Normal-Flow Function

Taint Analysis Example



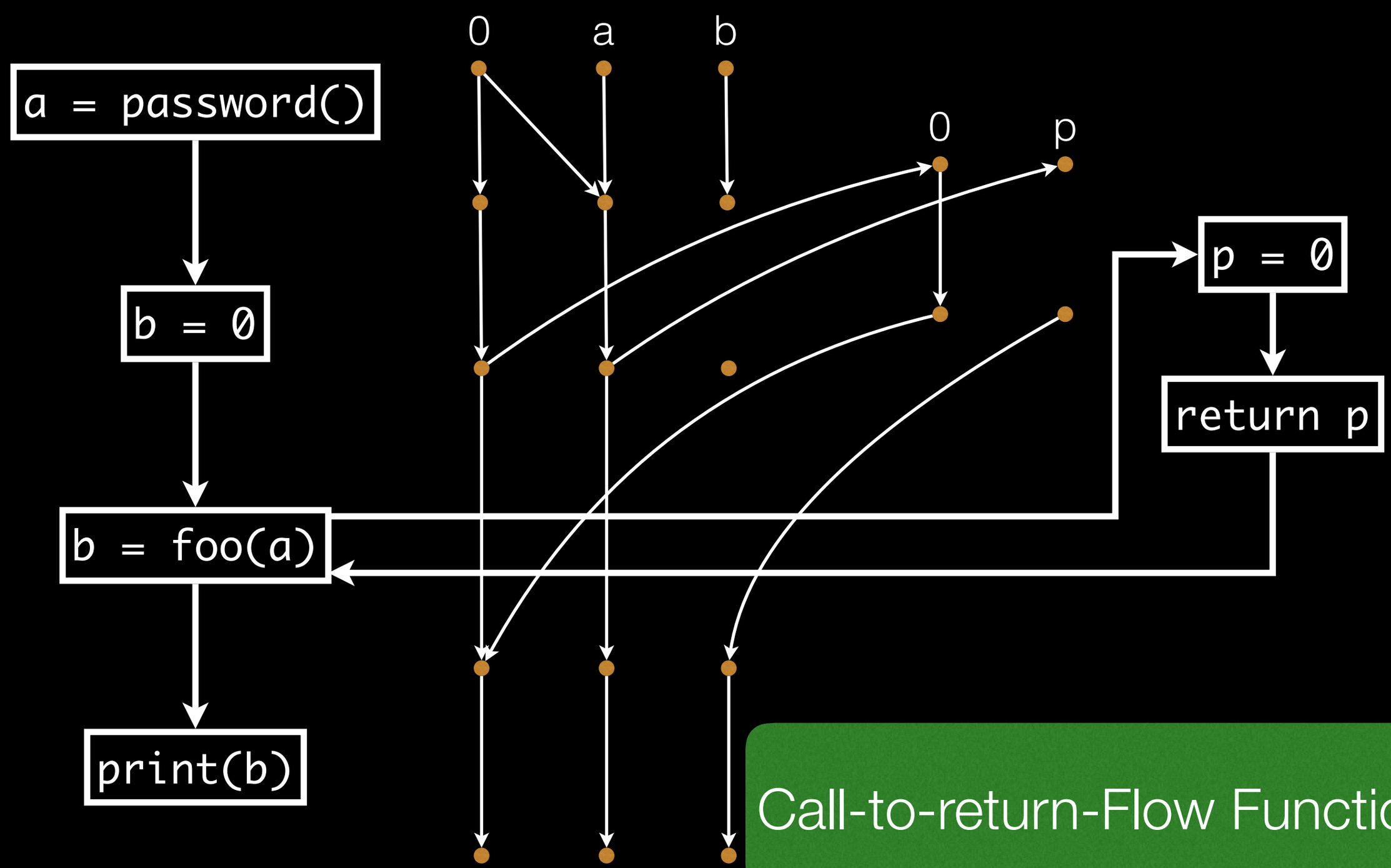
Return-Flow Function

Taint Analysis Example



Normal-Flow Function

Taint Analysis Example



Call-to-return-Flow Function

Flow Functions

Call-Flow Function

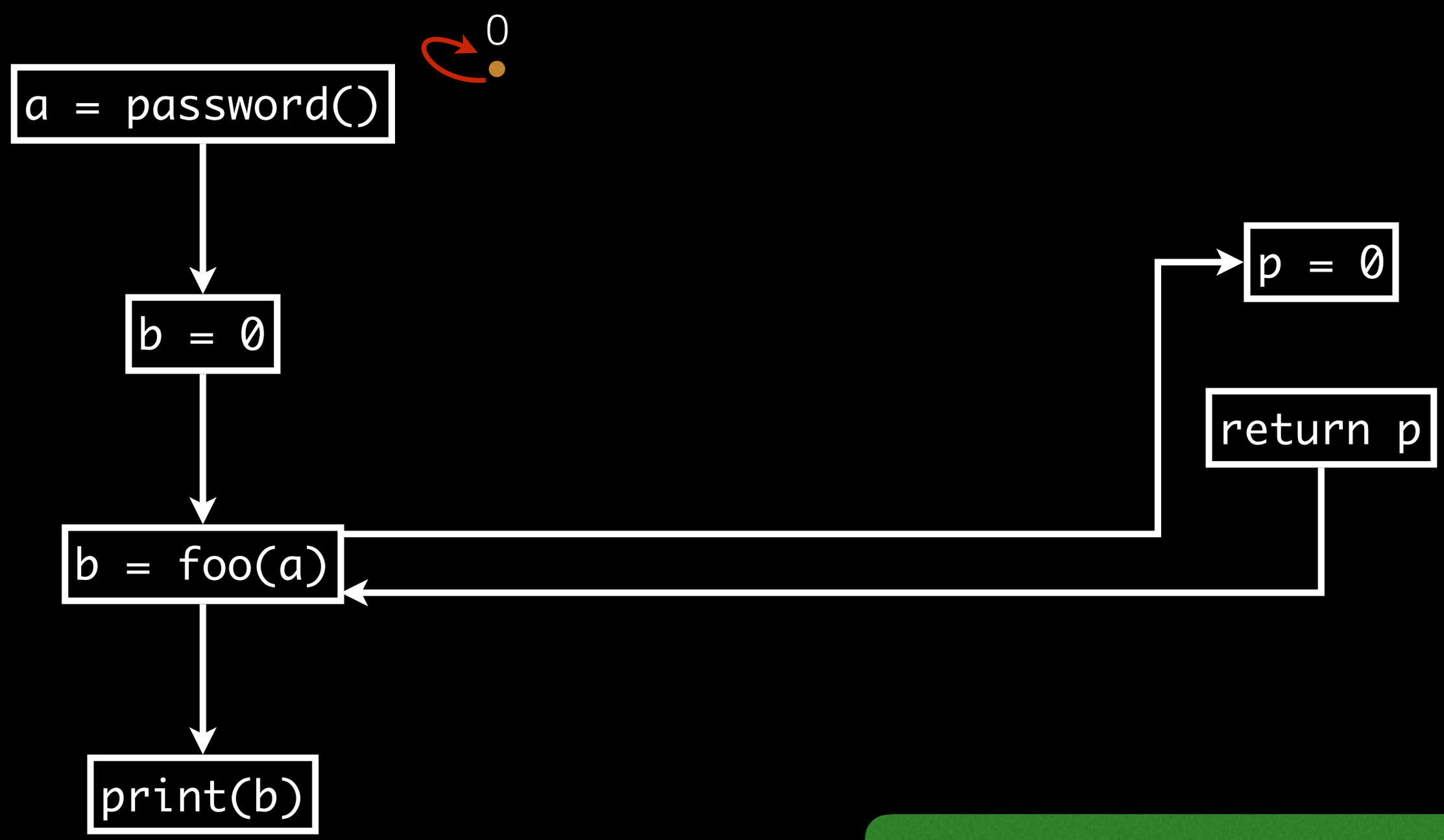
Normal-Flow Function

Return-Flow Function

id → Call-to-return-Flow Function

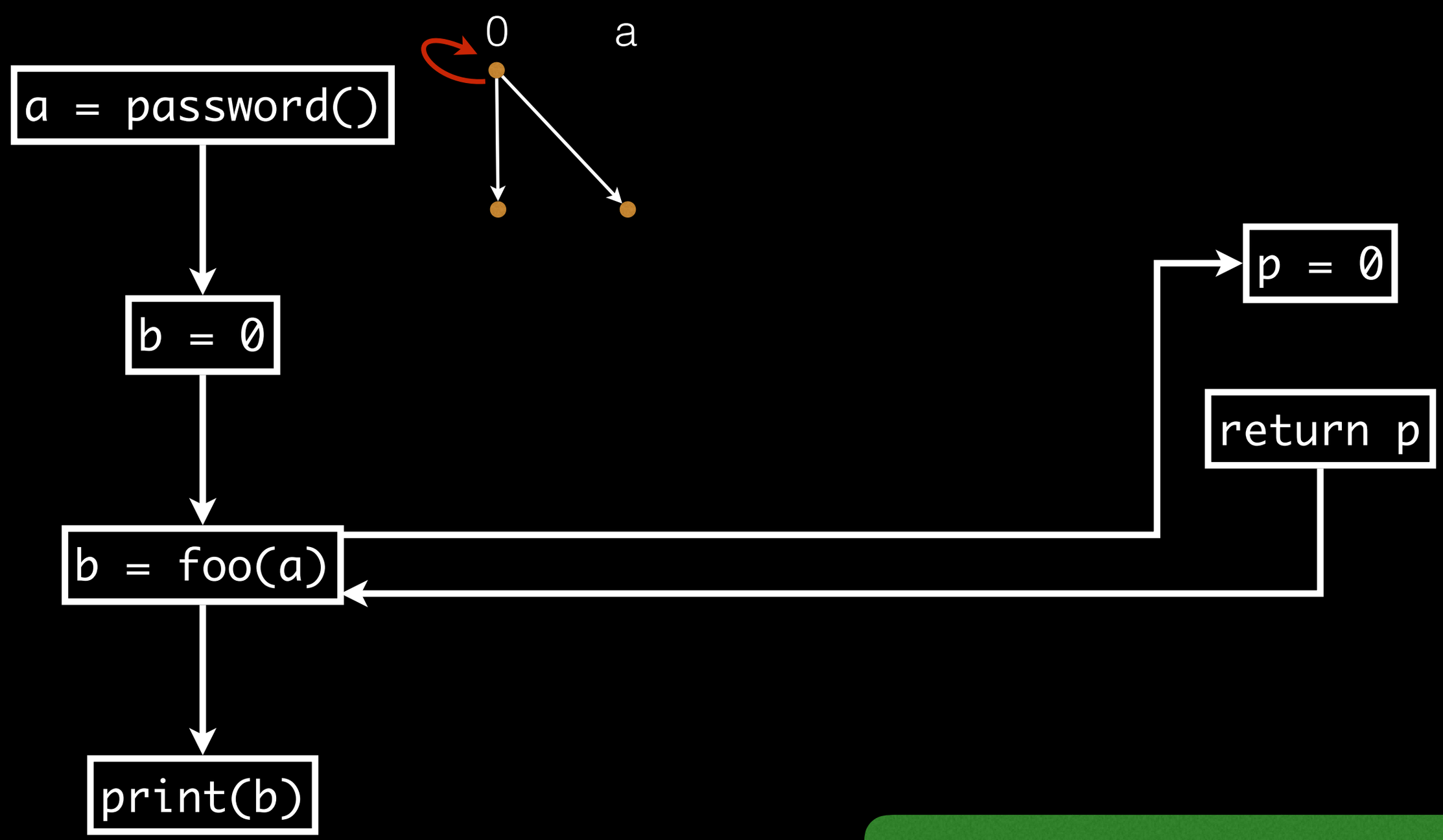
On-the-fly ESG

On-the-fly ESG



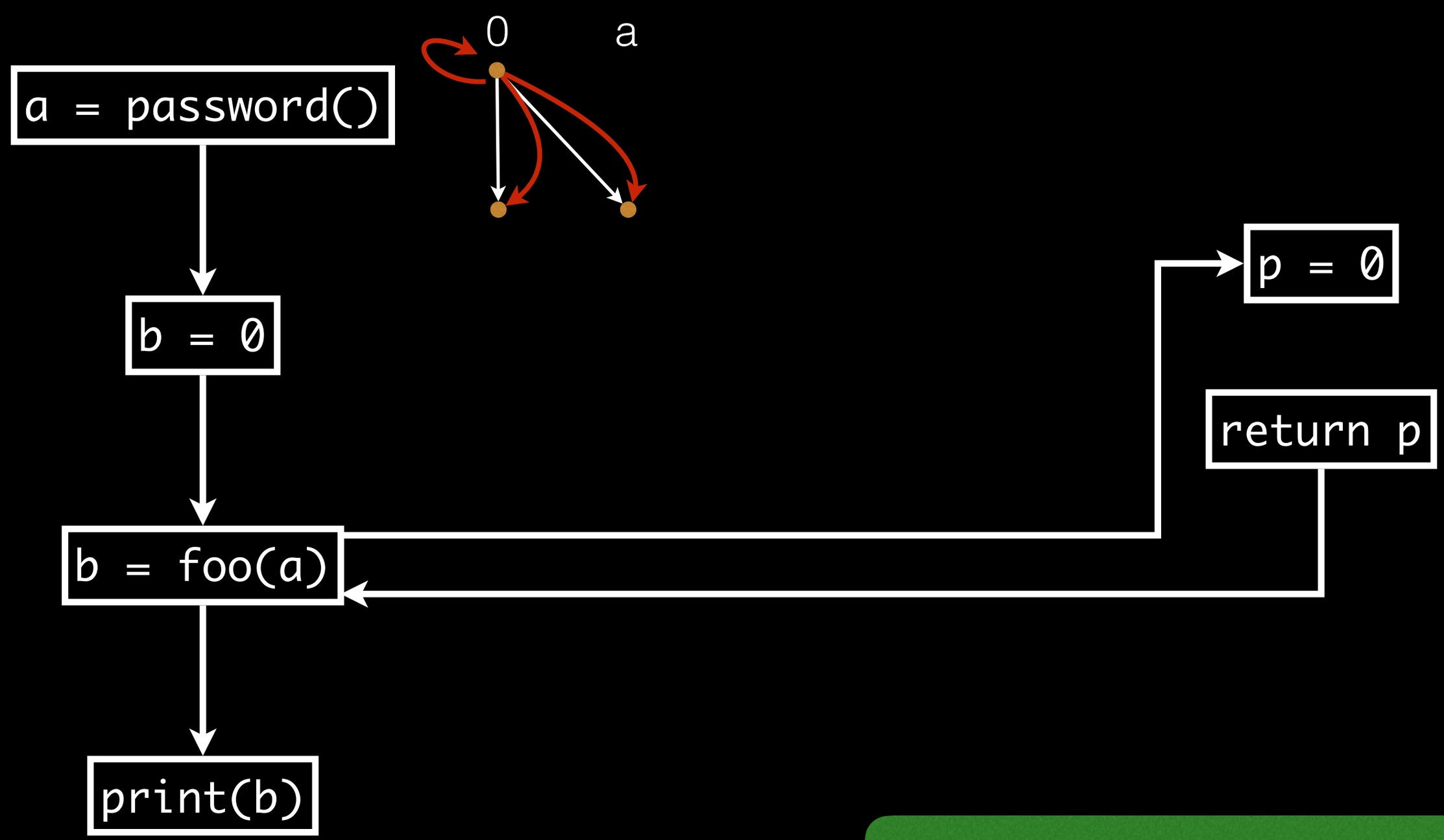
initial self-loop edge

On-the-fly ESG



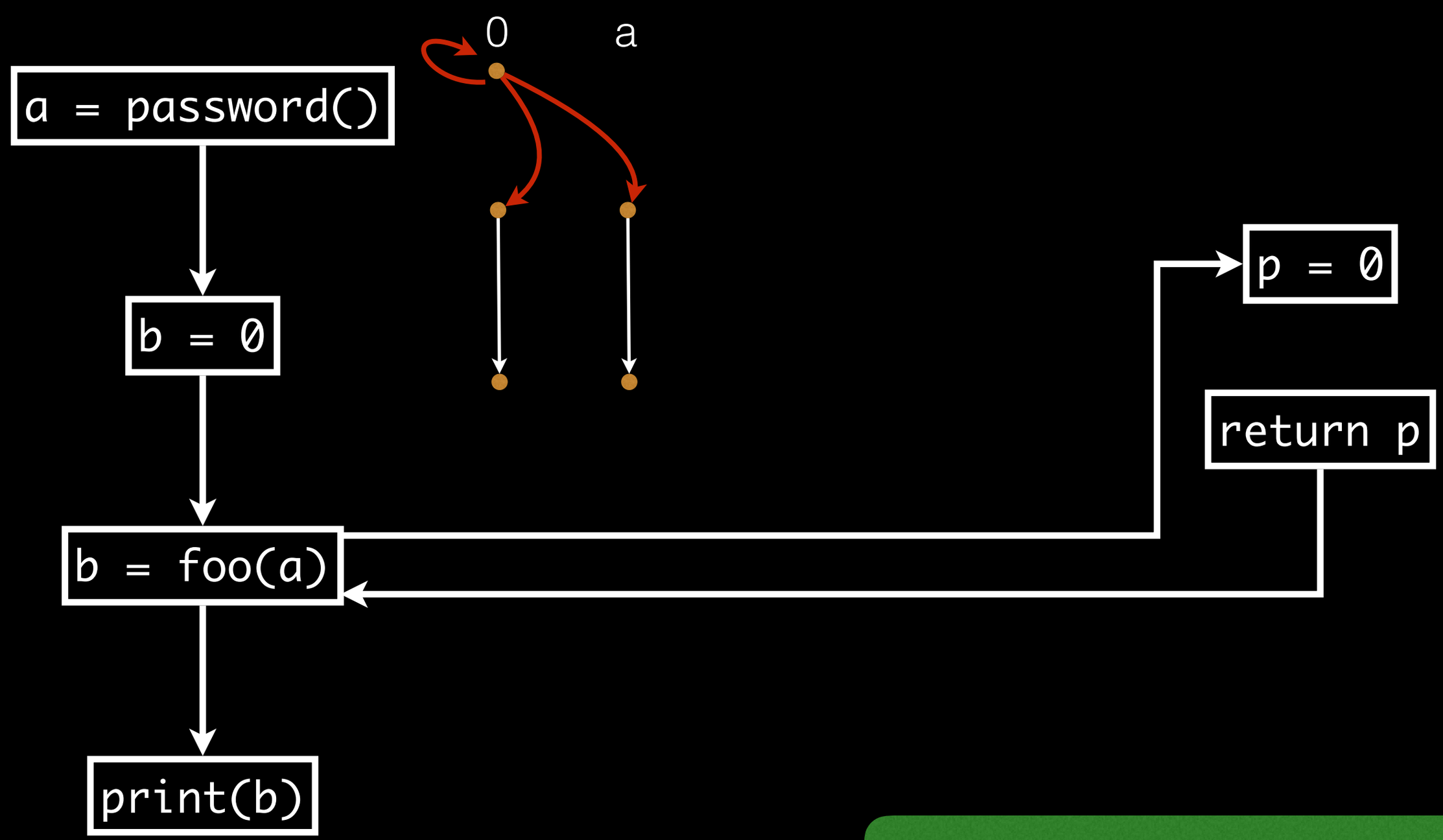
Normal-Flow

On-the-fly ESG



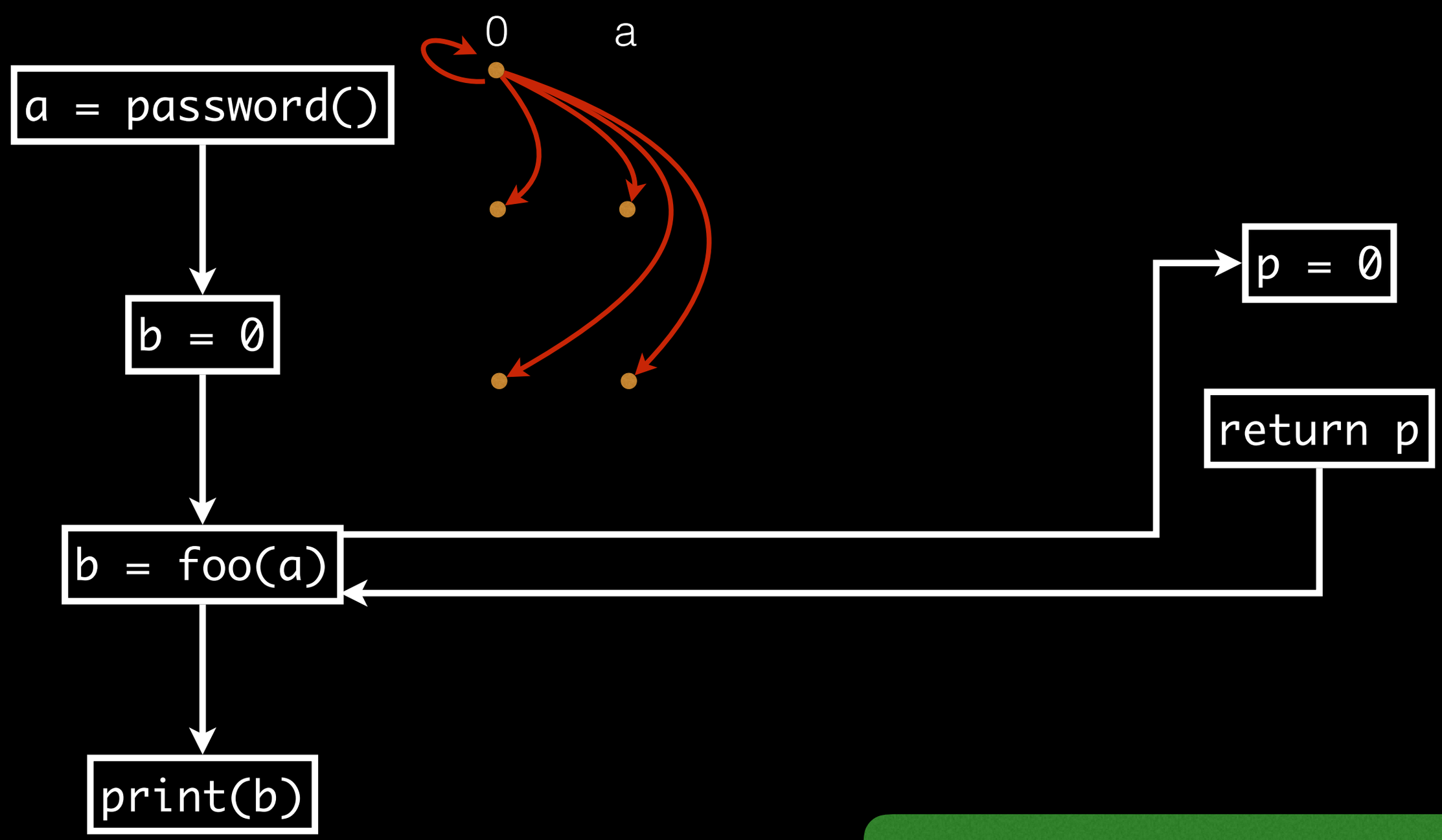
Path Edges

On-the-fly ESG



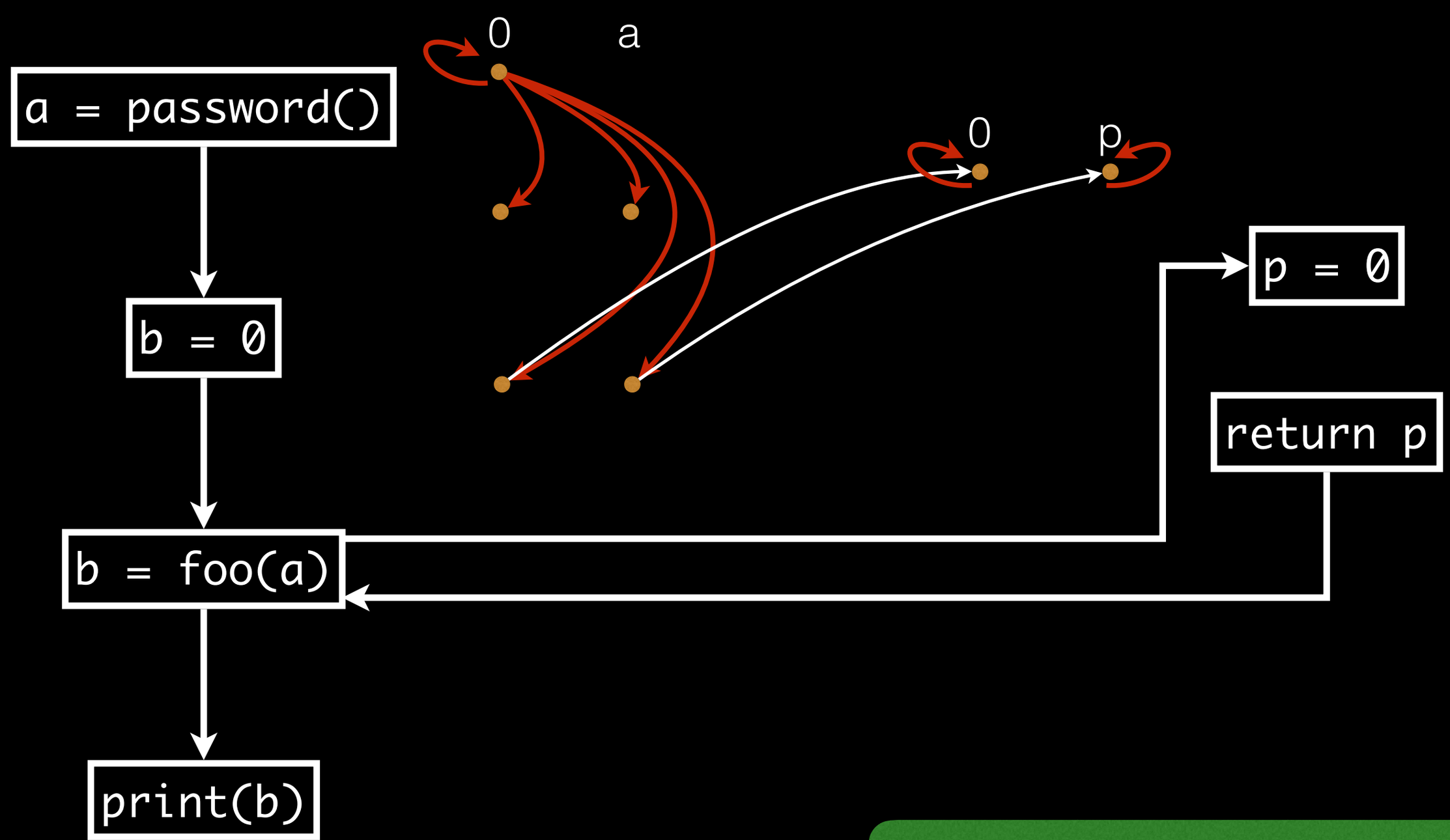
Normal-Flow

On-the-fly ESG



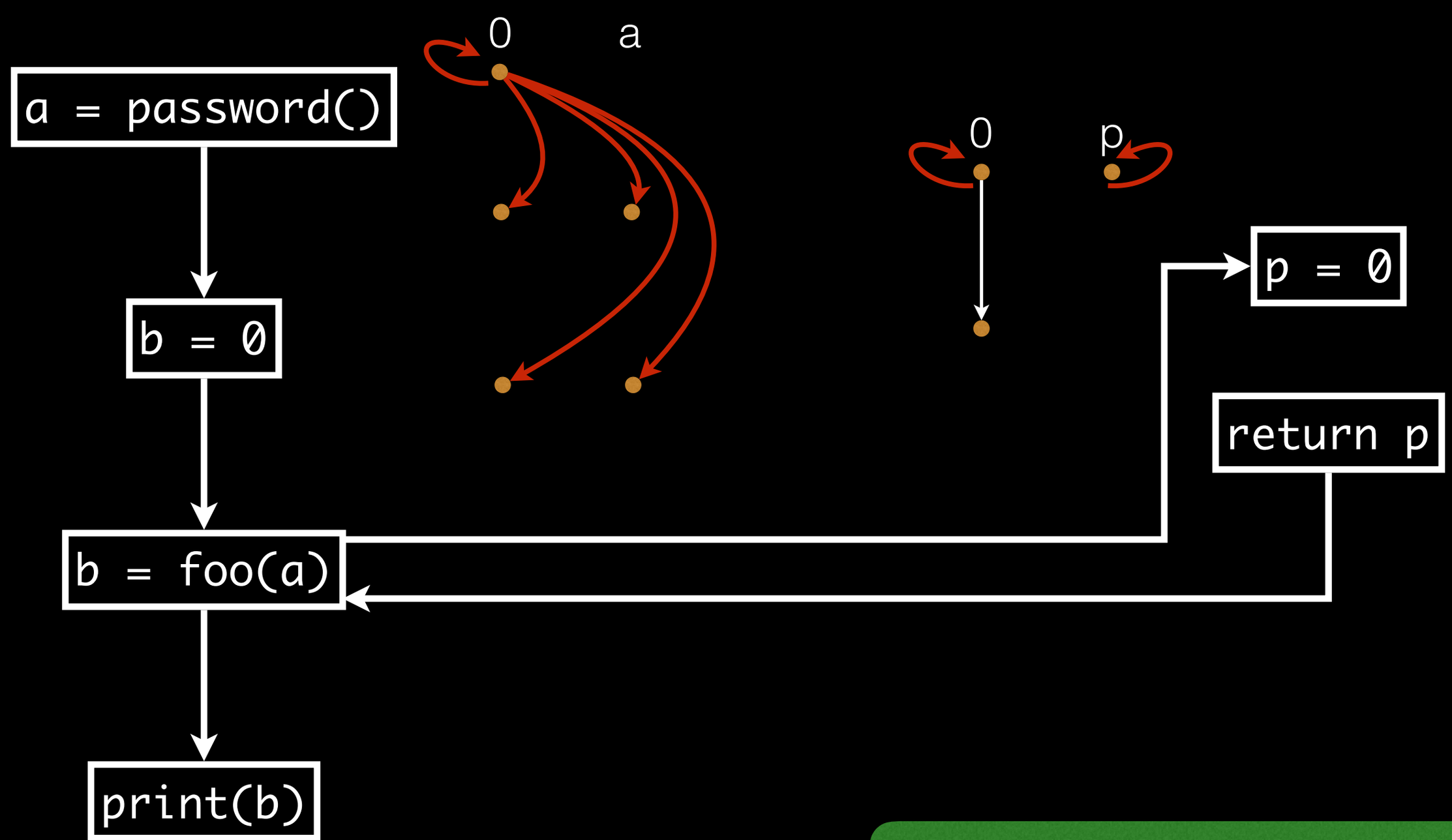
extend path edges

On-the-fly ESG



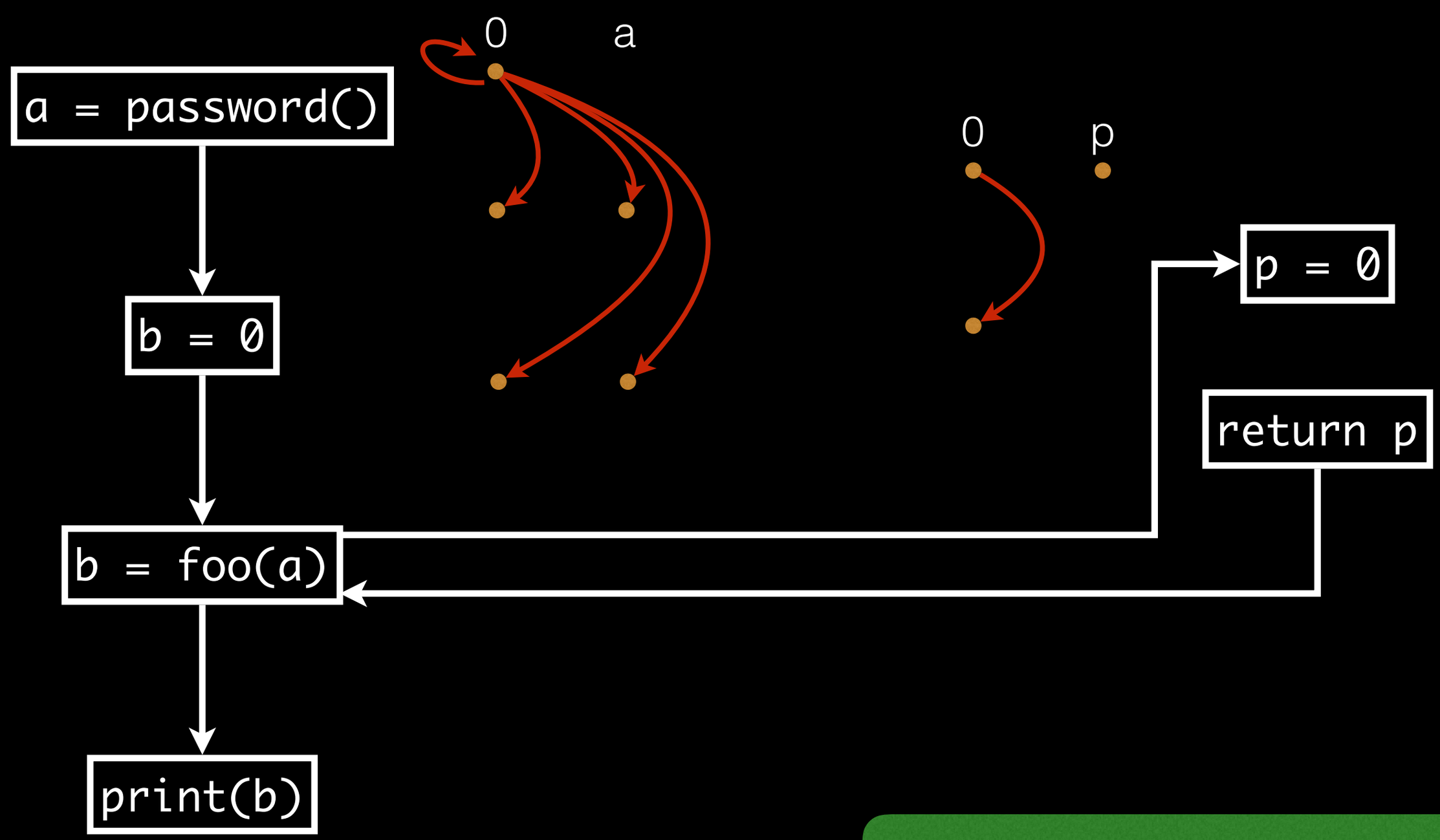
Call-Flow

On-the-fly ESG



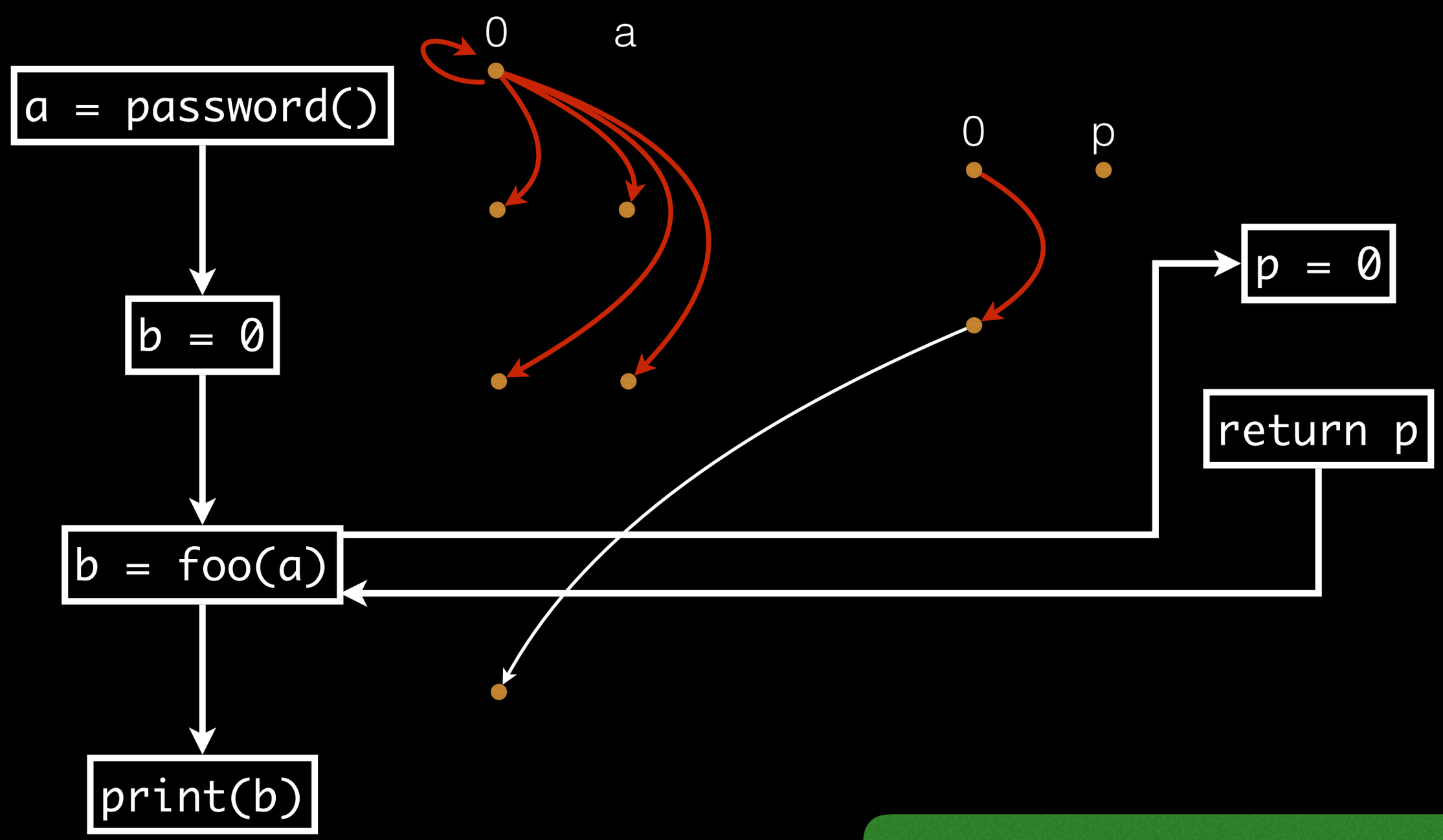
Normal-Flow

On-the-fly ESG



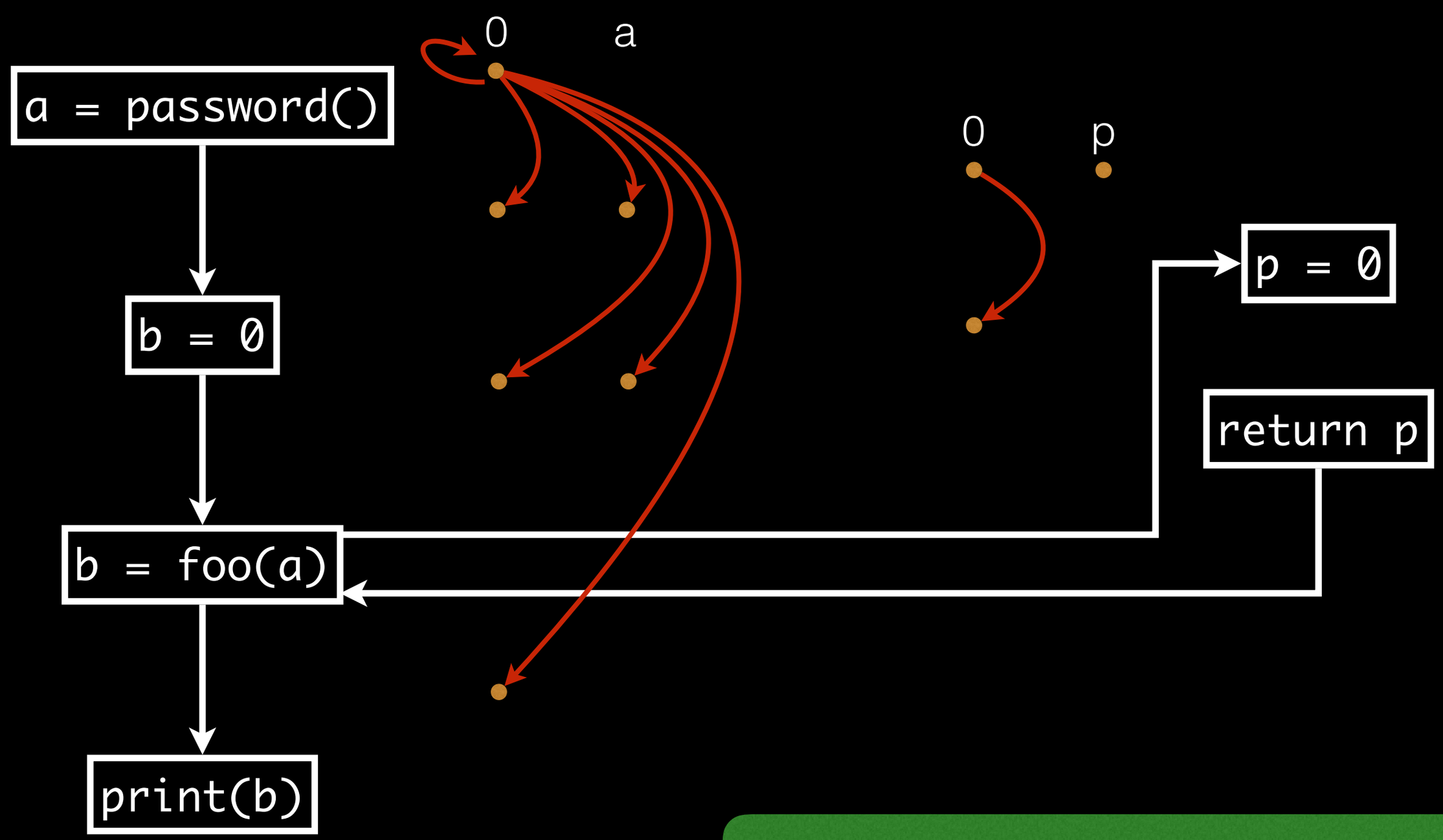
Method Summary

On-the-fly ESG



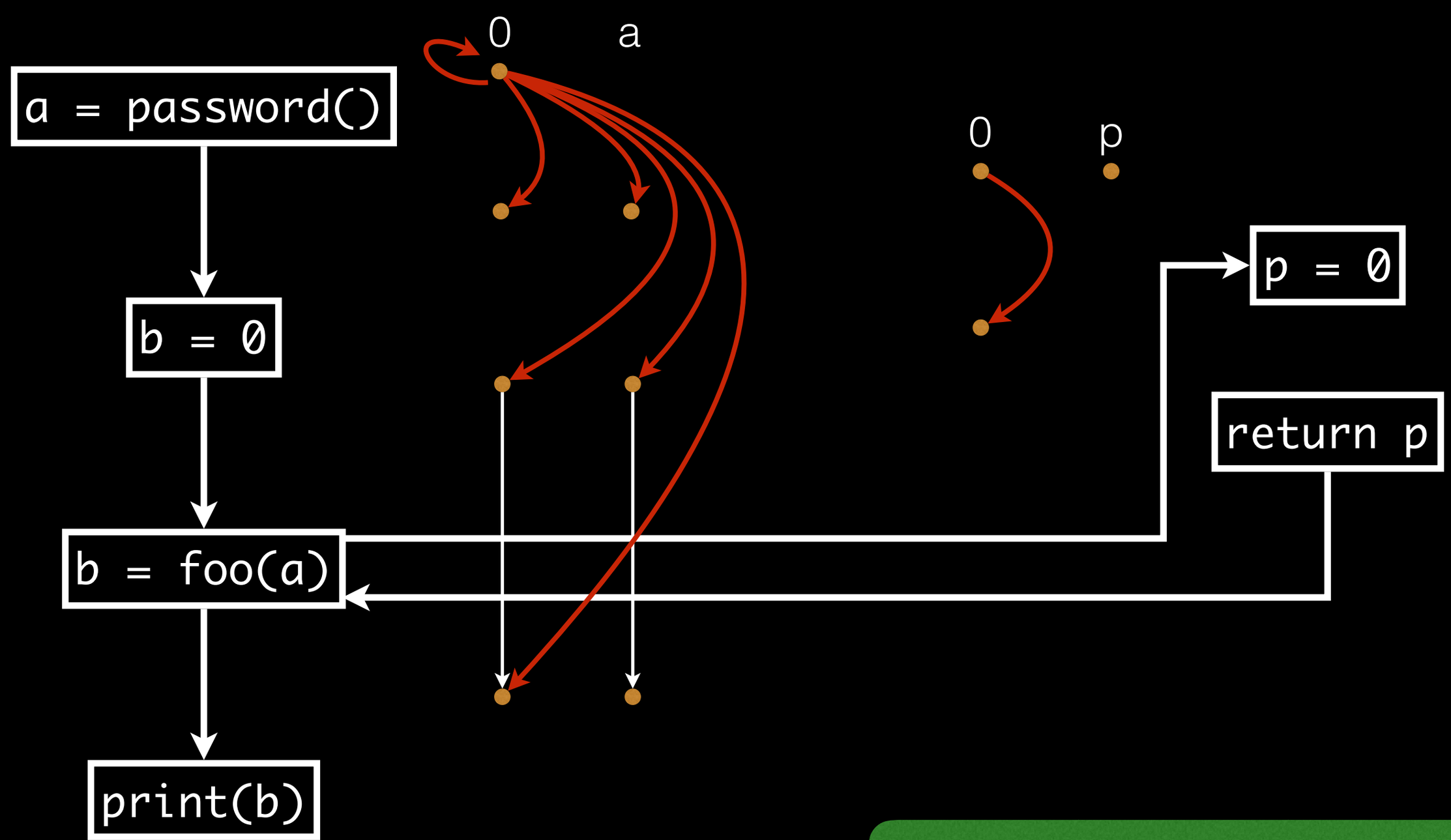
Return-Flow

On-the-fly ESG



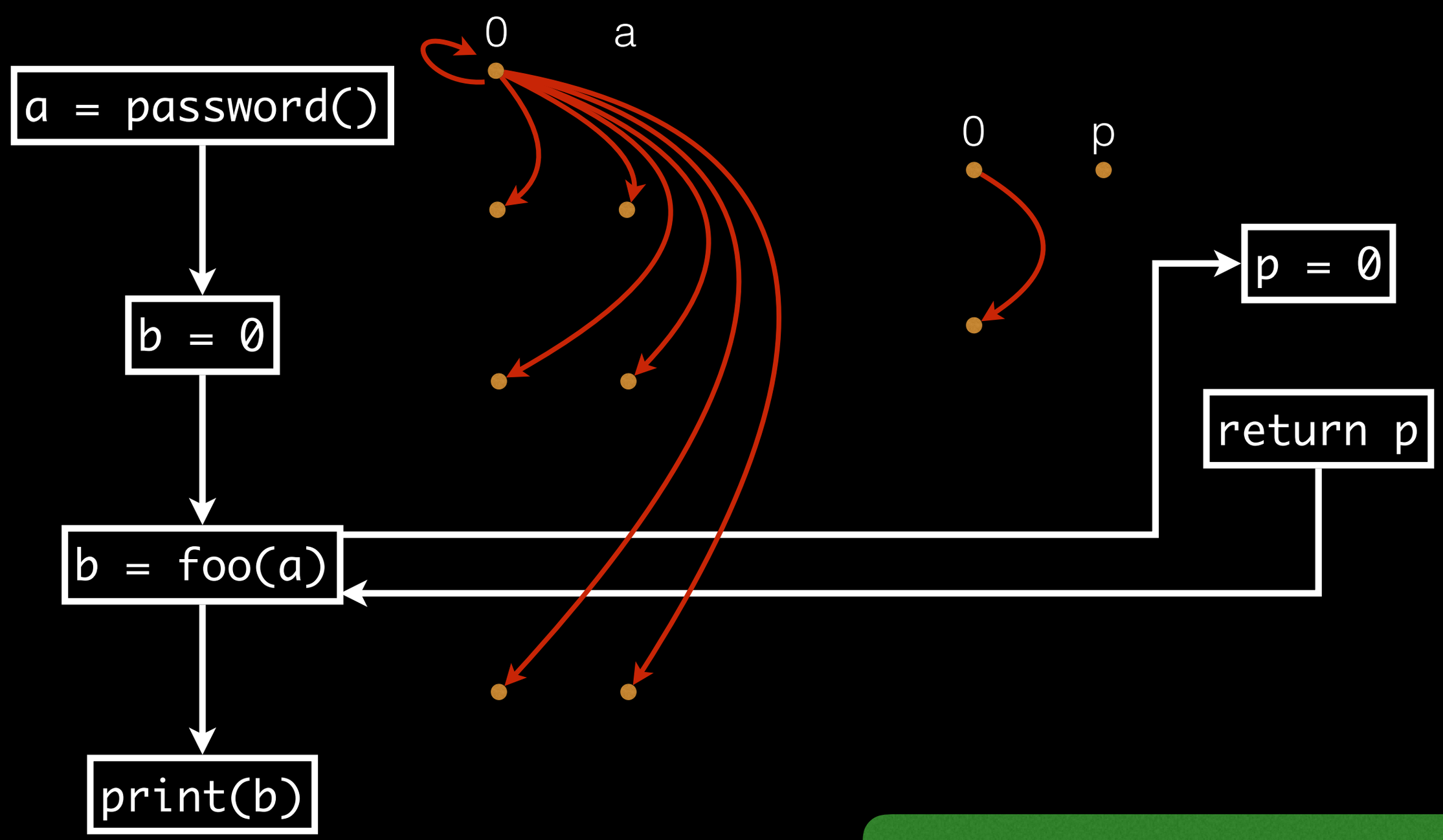
extend path edges in caller

On-the-fly ESG



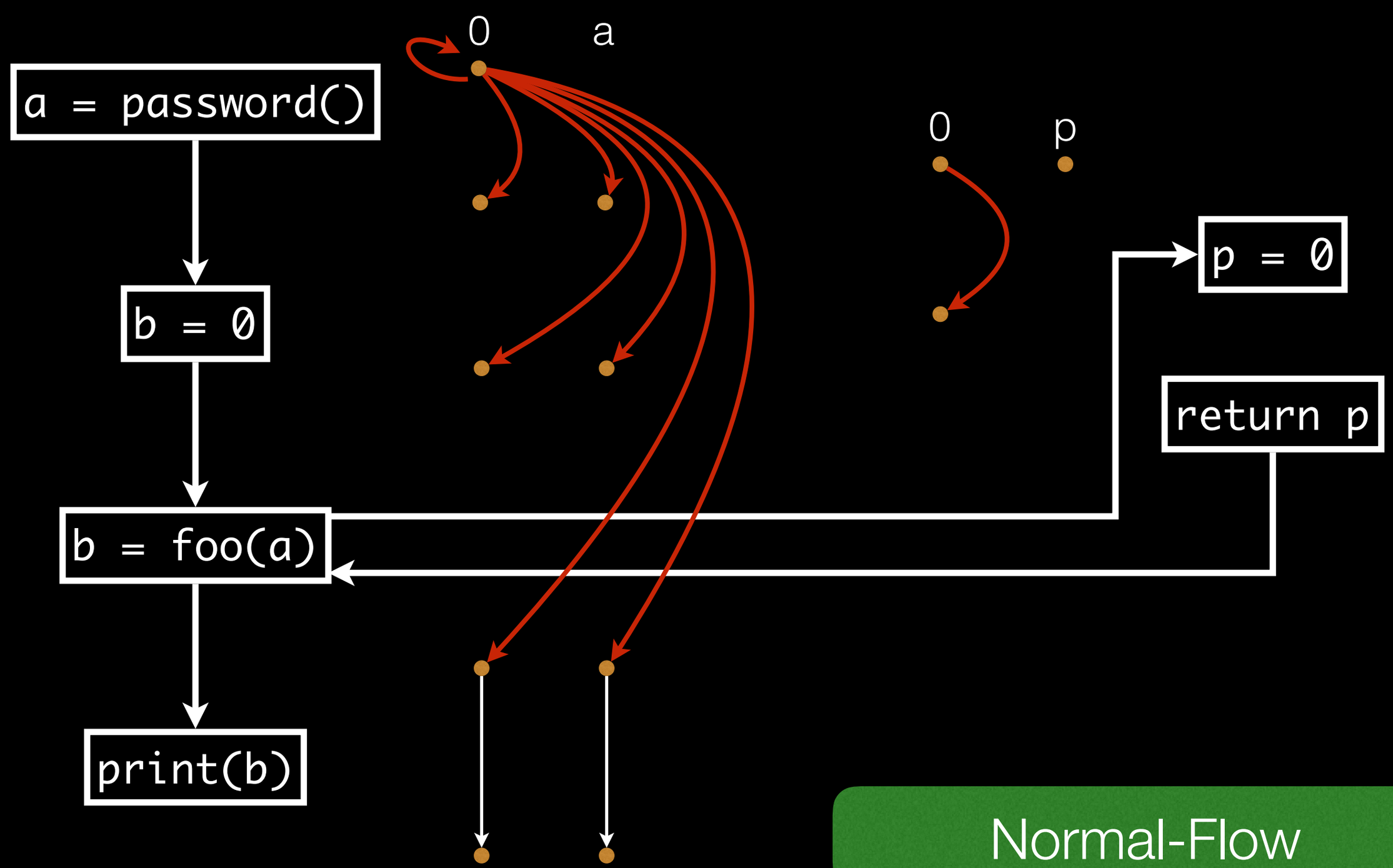
Call-to-return

On-the-fly ESG



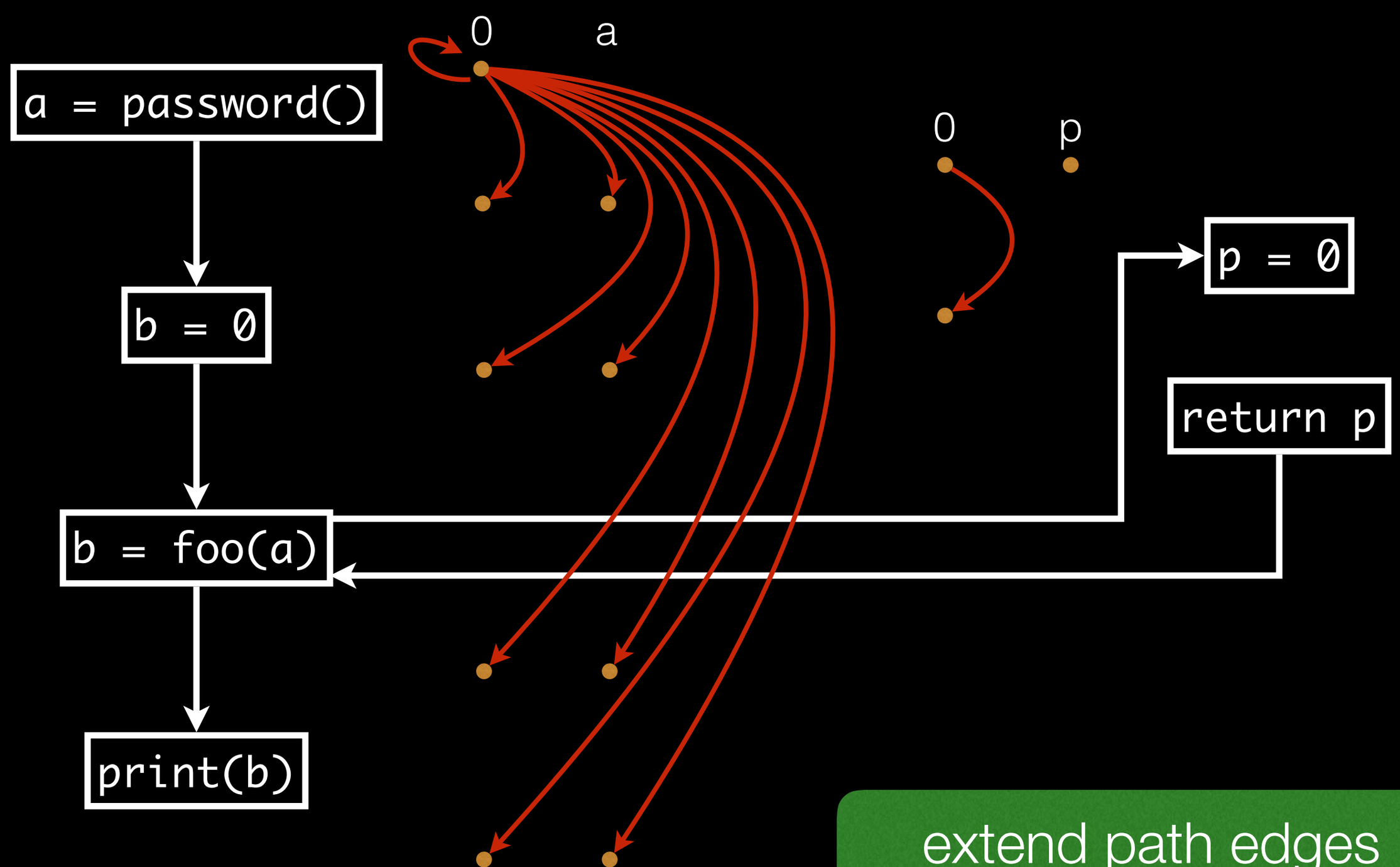
extend path edges

On-the-fly ESG



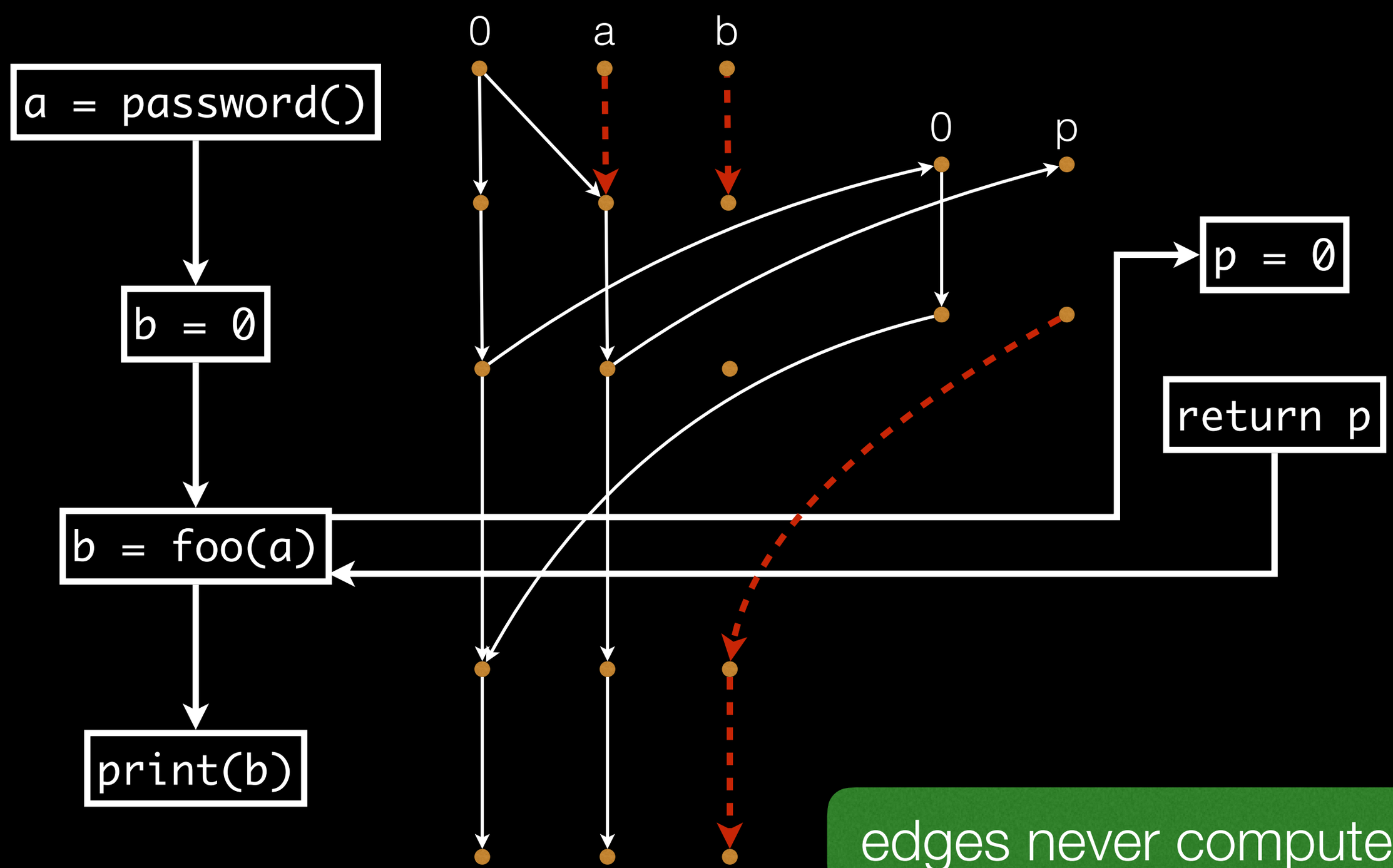
Normal-Flow

On-the-fly ESG



extend path edges

On-the-fly ESG



edges never computed

Tidbits!

Field-Sensitivity

a.f	a.*	A.f
Field-Sensitive	Field-Insensitive	Field-Based

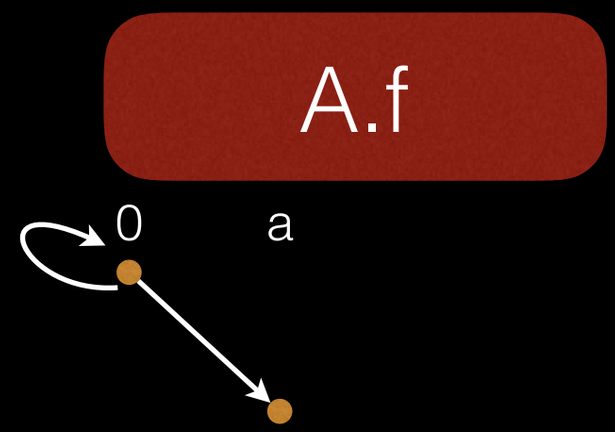
Field-Based

A.f


```
a = source();

b = new DS();

c = new DS();

b.f = a;

d = c.f

sink(d);
```

D = Locals ∪ Fields

Field-Based

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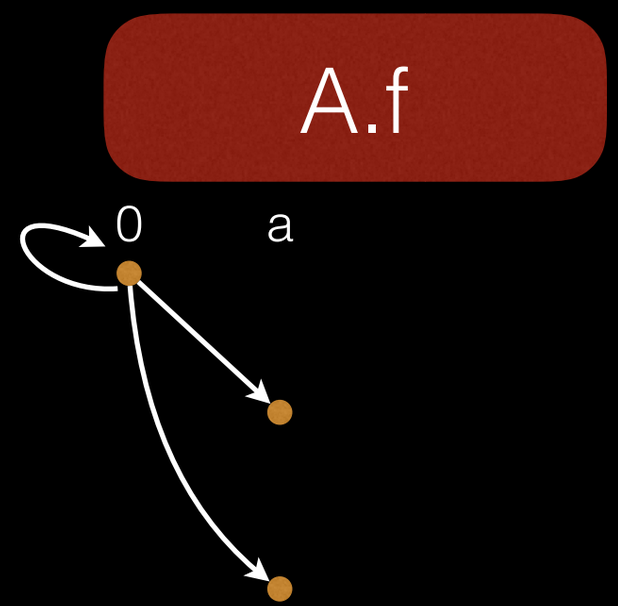

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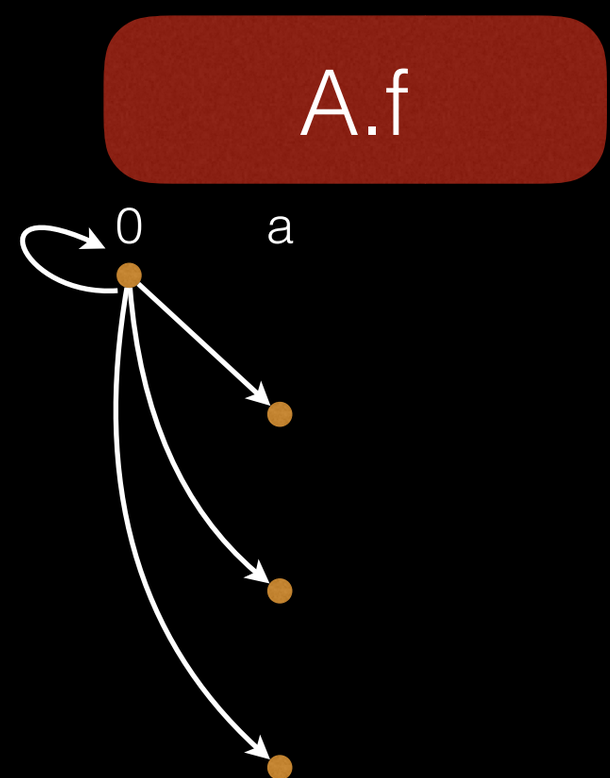

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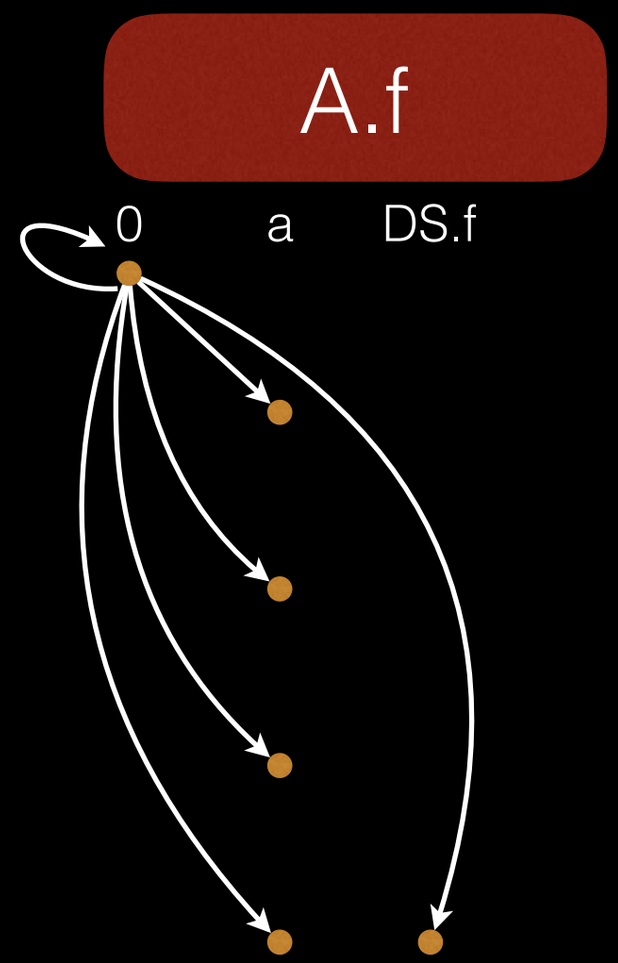

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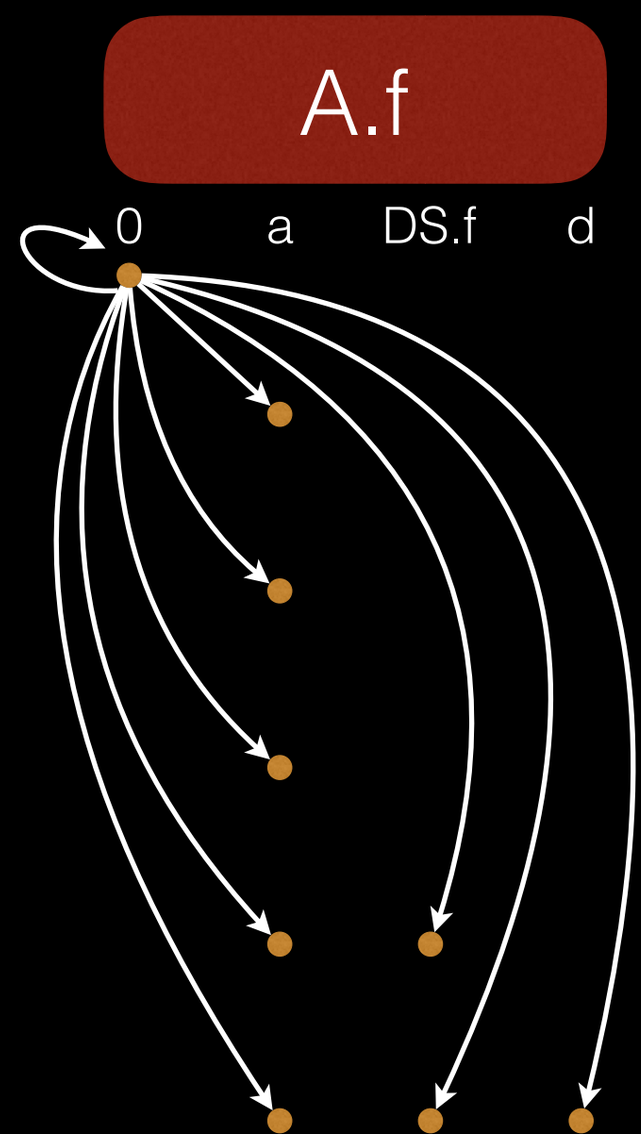
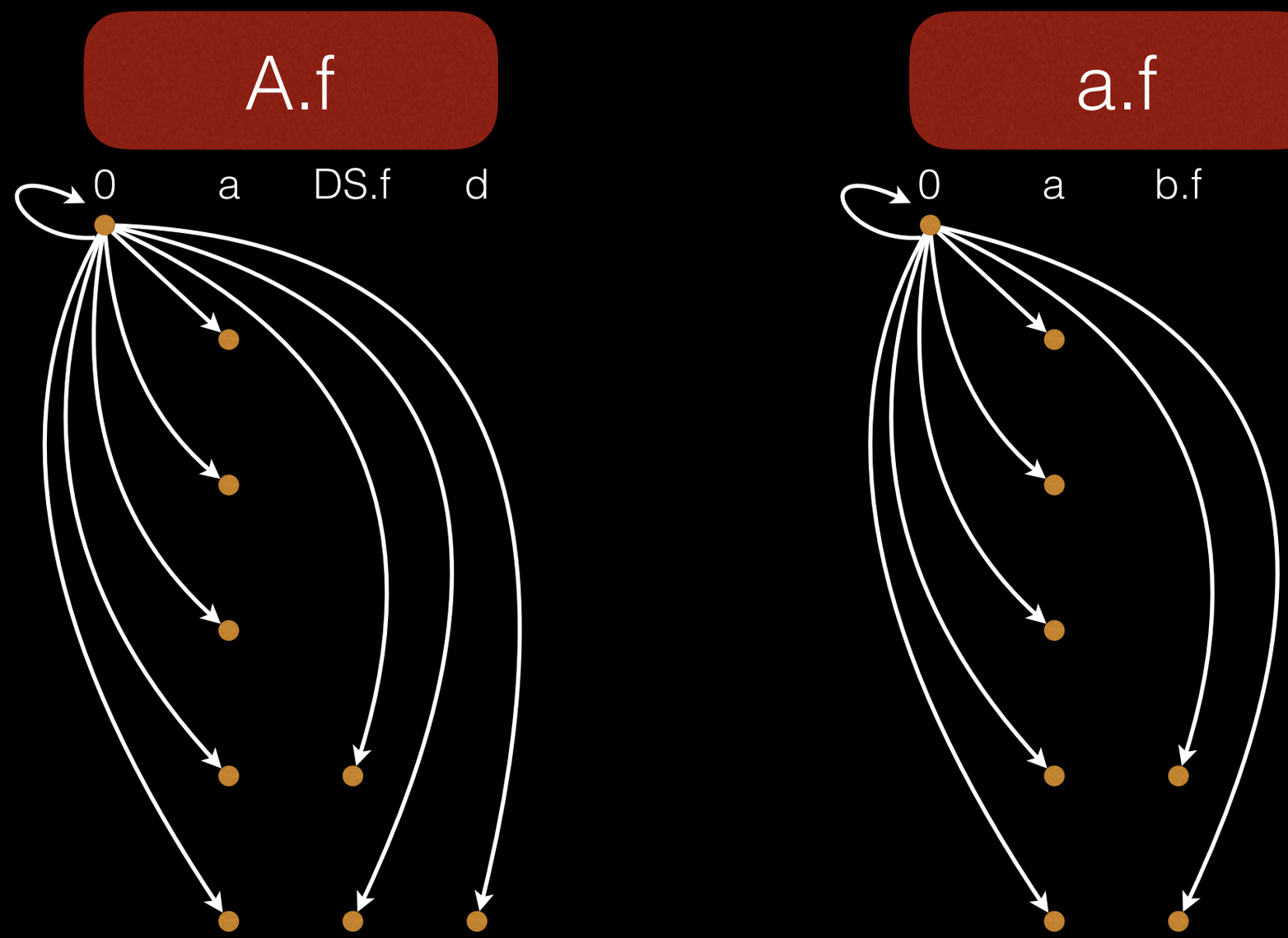


D = Locals ∪ Fields

Field-Sensitive

```
a = source();

b = new DS();

c = new DS();

b.f = a;

d = c.f

sink(d);
```



$D = \{l.f_1.f_2.f_3. \ldots .f_n\}$
$l \in Locals$, $f_i \in fields$
$n \geq 0$

Field-Sensitive

```
a = source();

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d = c.f

sink(d);
```
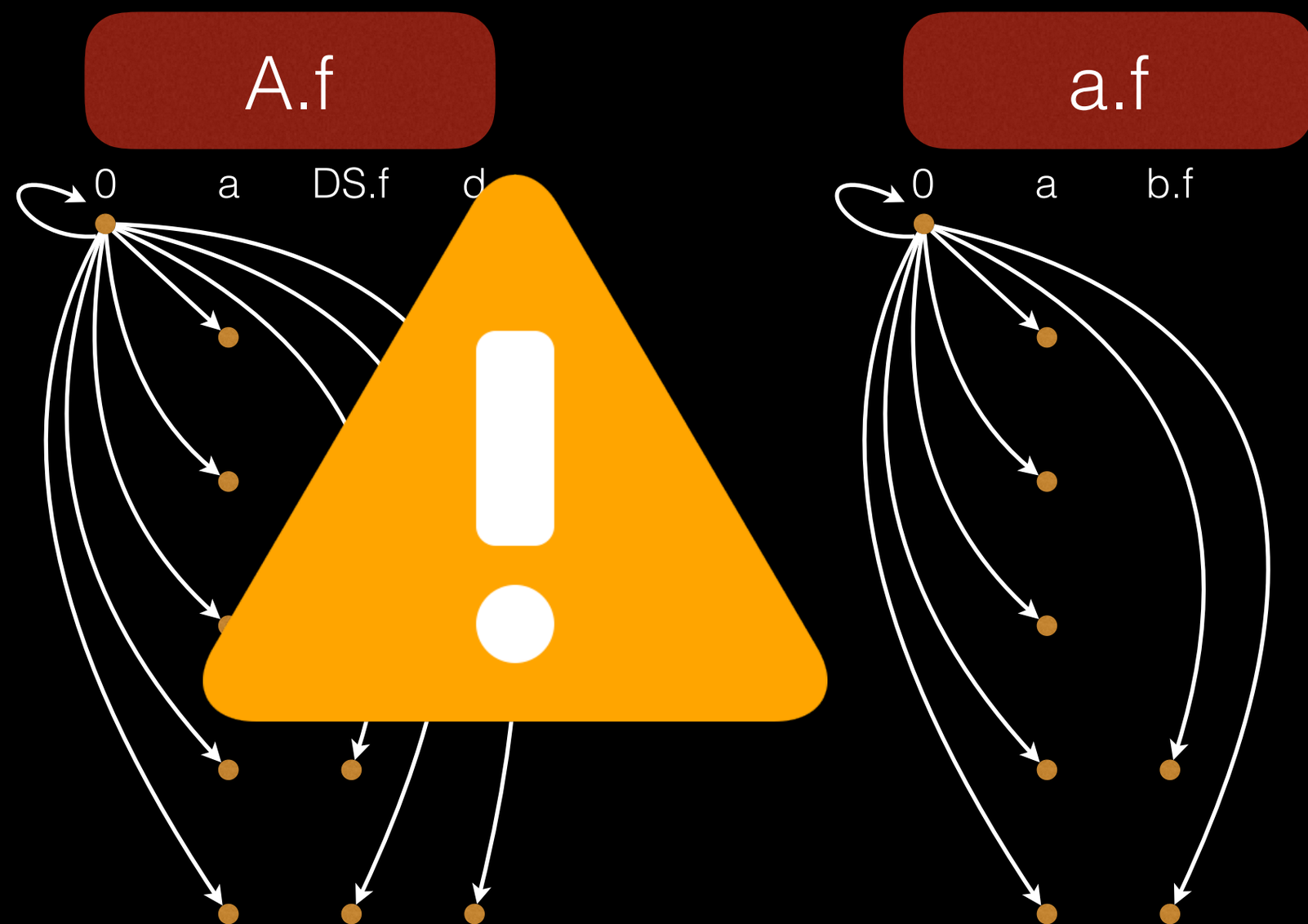
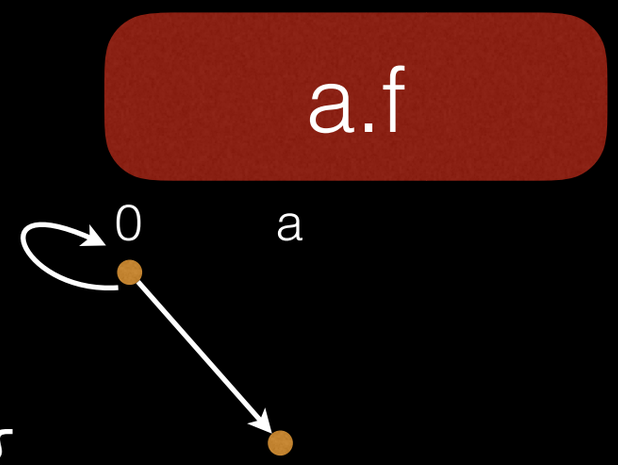



Infinite domain!!

$D = \{l.f_1.f_2.f_3. \ldots .f_n\}$
$l \in$ Locals, $f_i \in$ fields
$n \geq 0$

Field-Sensitive




```
a = source();

while(rand()) {

  b = new DS();

  b.f = a;

  a = b;
}

sink(d);
```

$D = \{l.f_1.f_2.f_3. \ldots .f_n\}$
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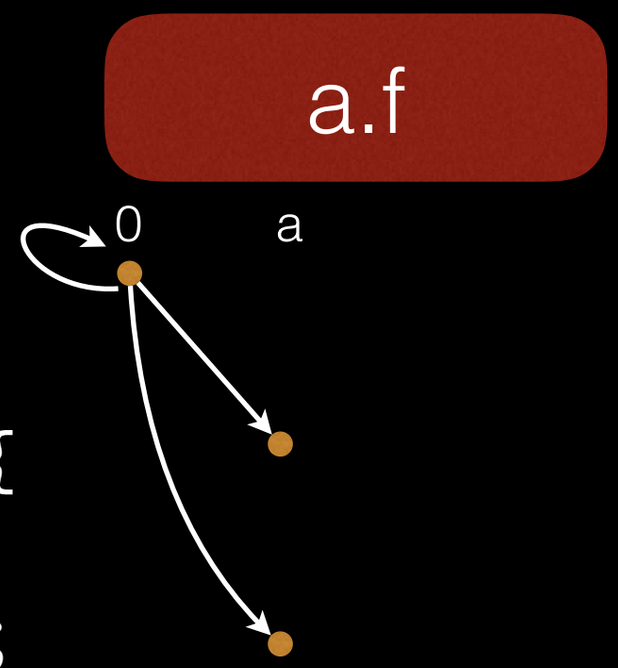

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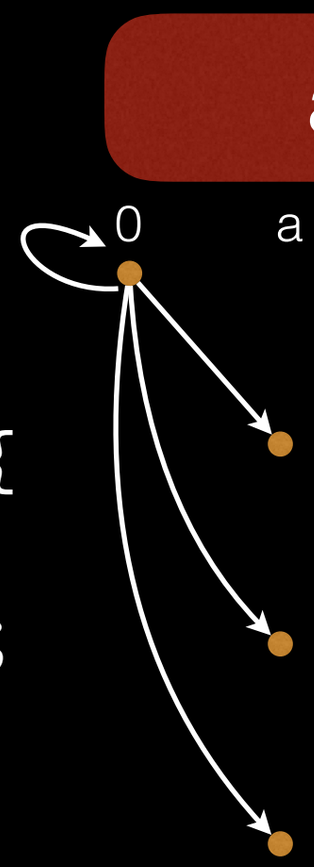

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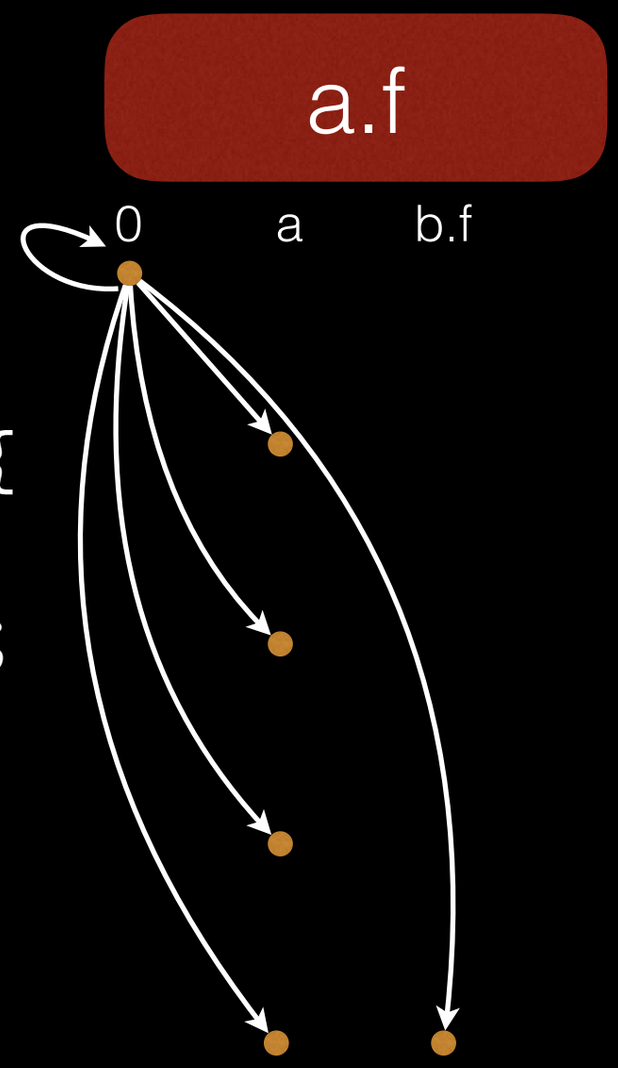

$D = \{l.f_1.f_2.f_3. \ldots .f_n\}$
$l \in$ Locals, $f_i \in$ fields
$n \geq 0$

Field-Sensitive

```
a = source();

while(rand()) {

  b = new DS();

  b.f = a;

  a = b;
}

sink(d);
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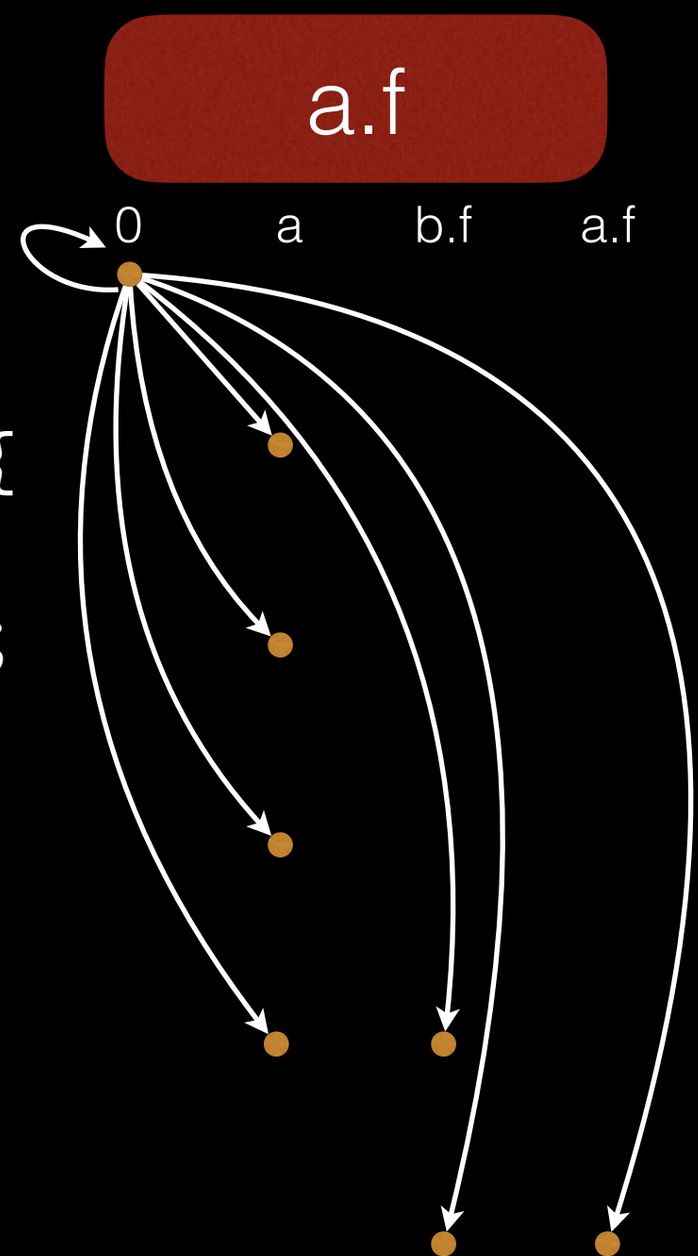

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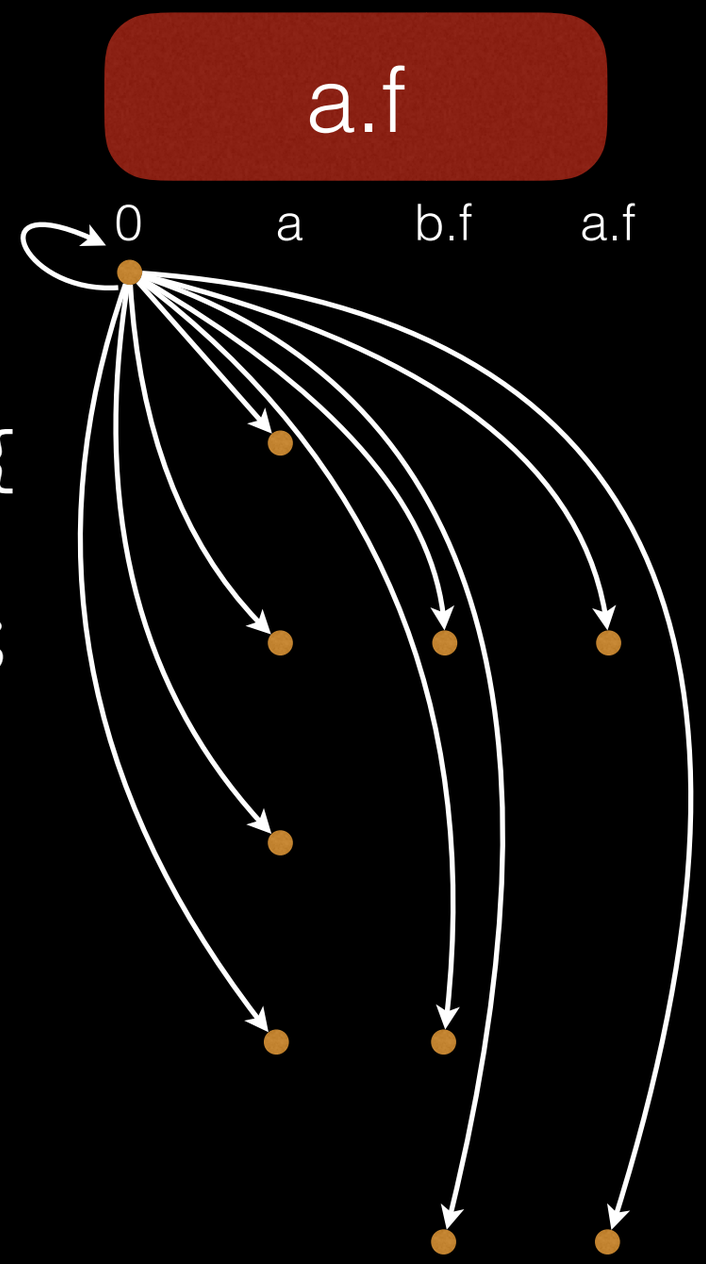

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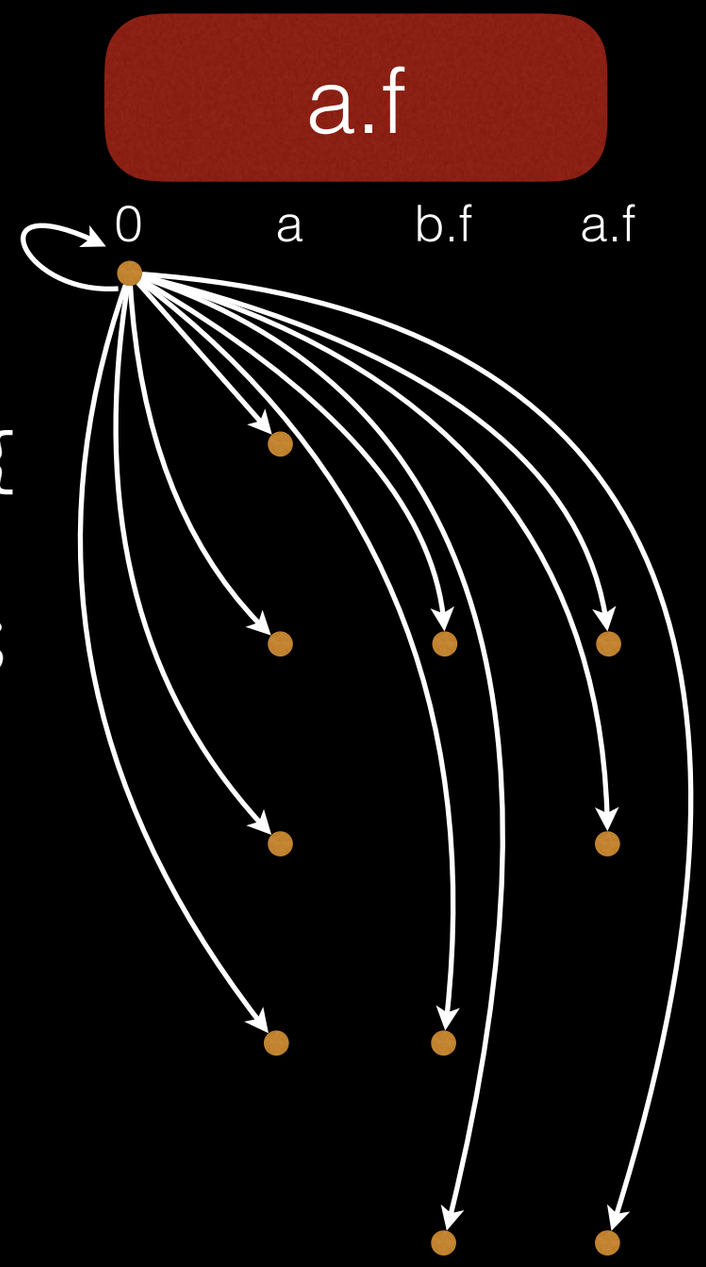

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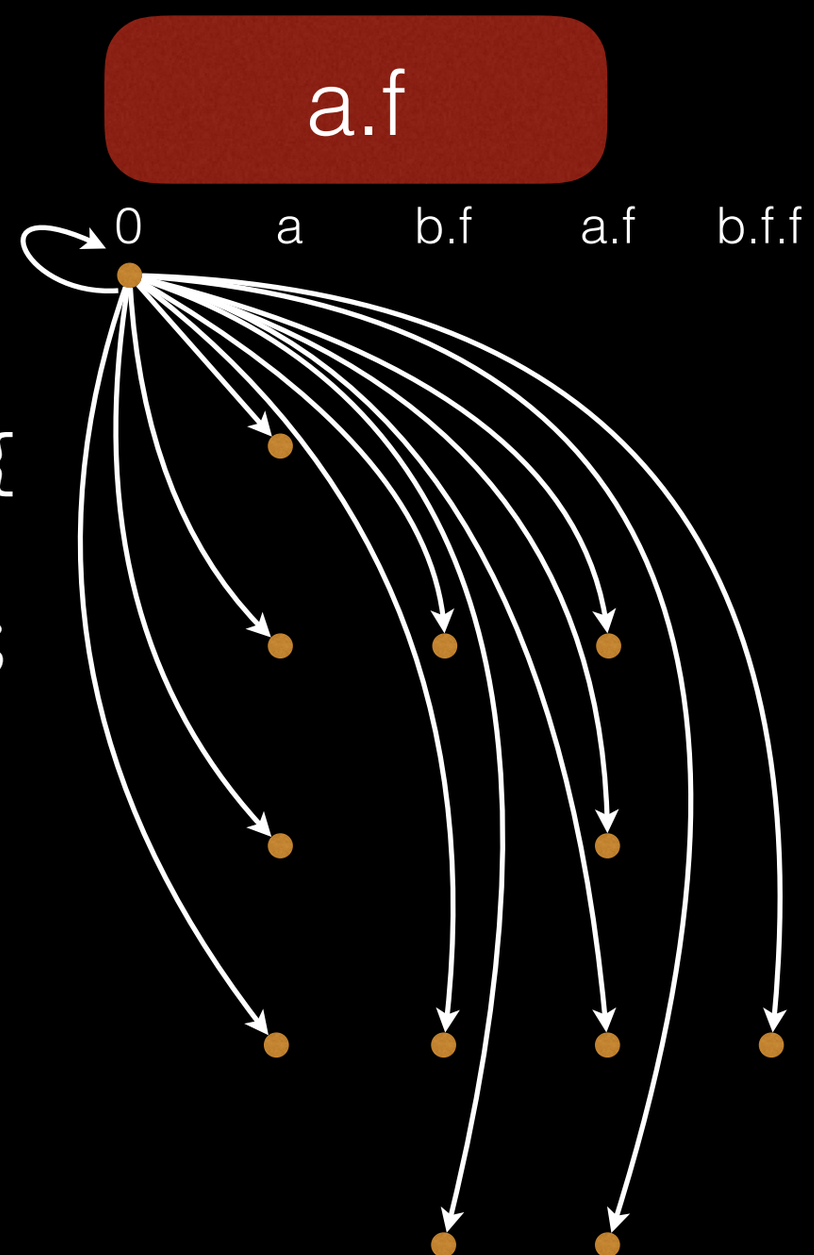

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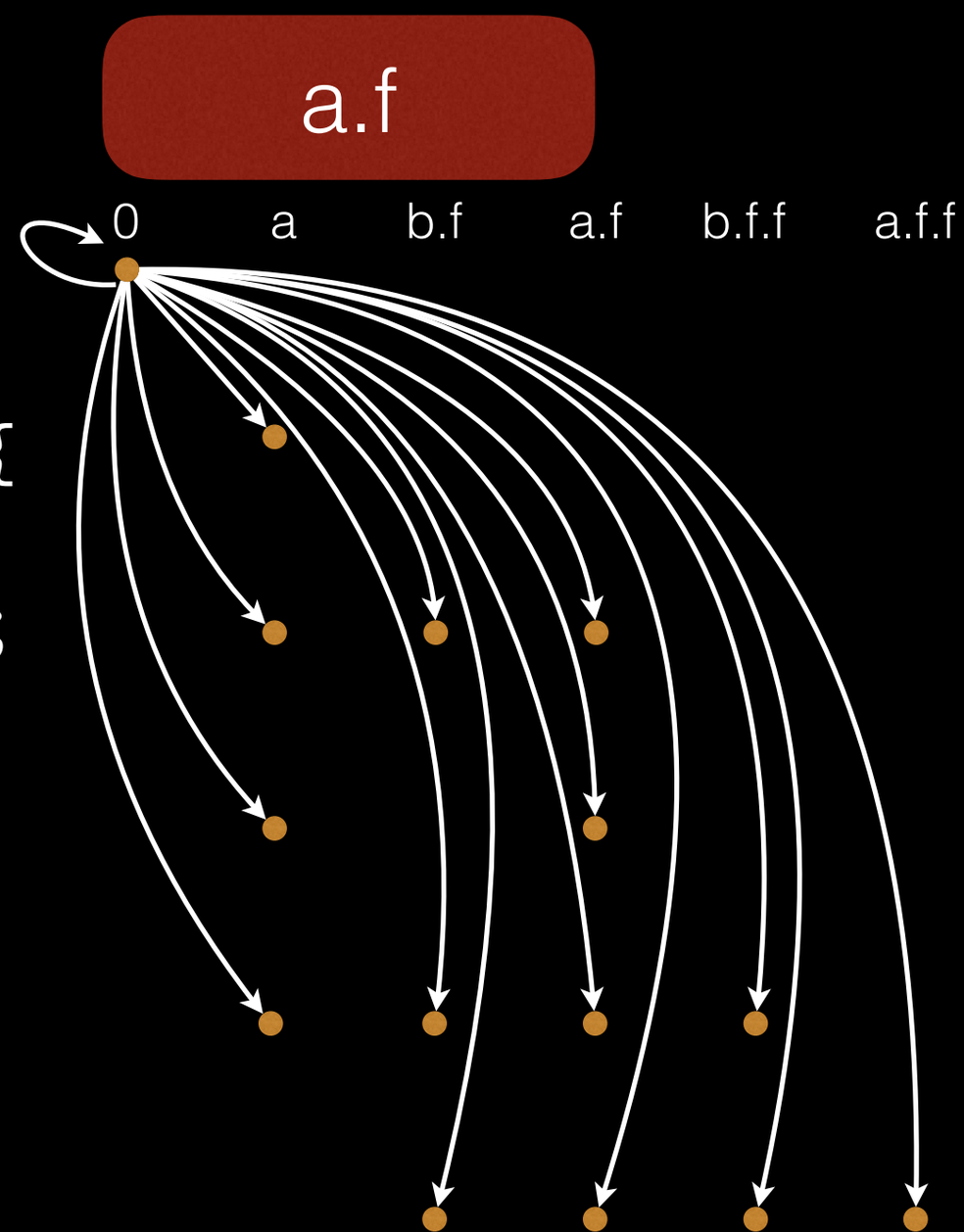

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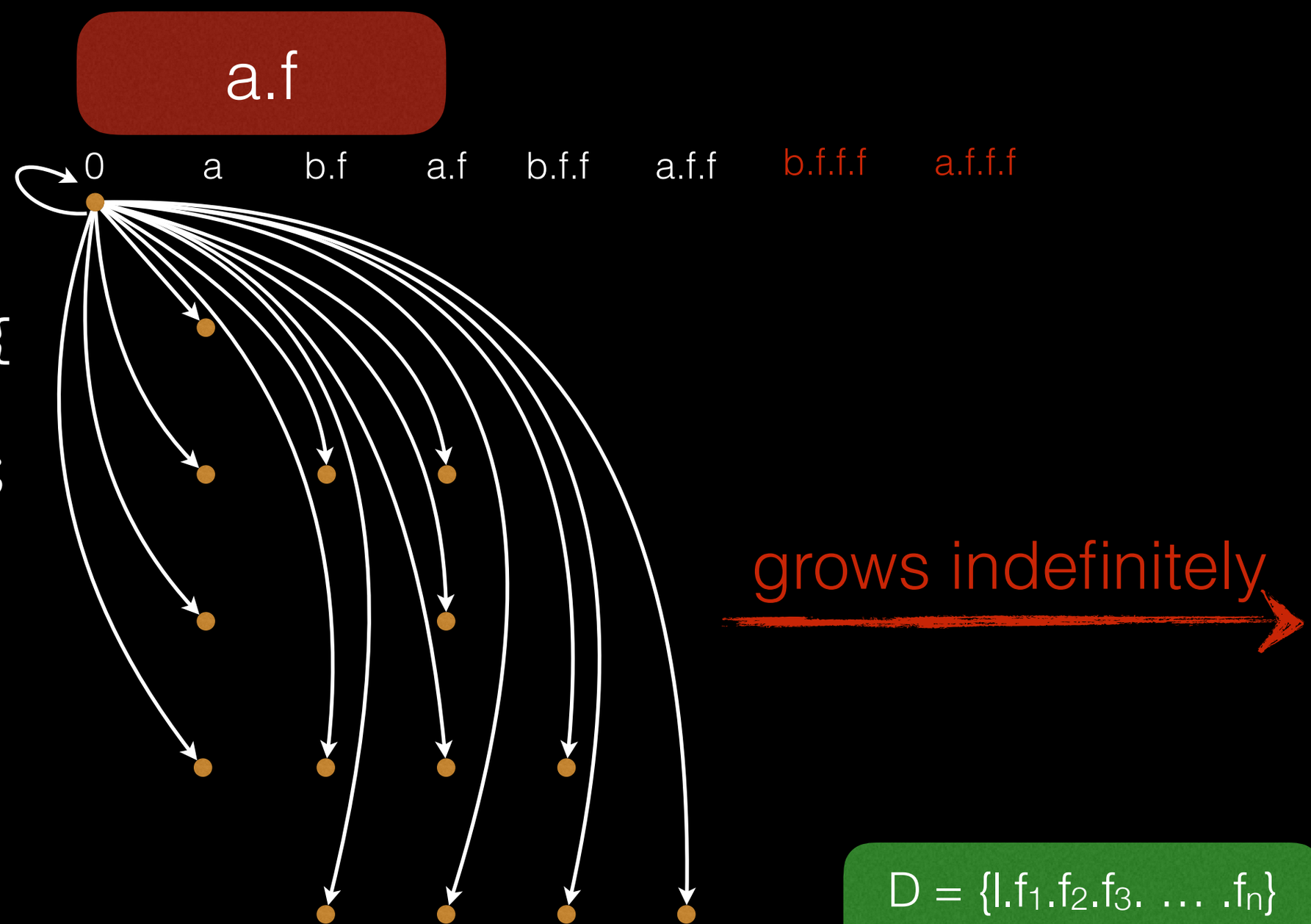

$D = \{l.f_1.f_2.f_3. \ldots .f_n\}$
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$n \geq 0$

k-Limiting

```
a = source();

while(rand()) {

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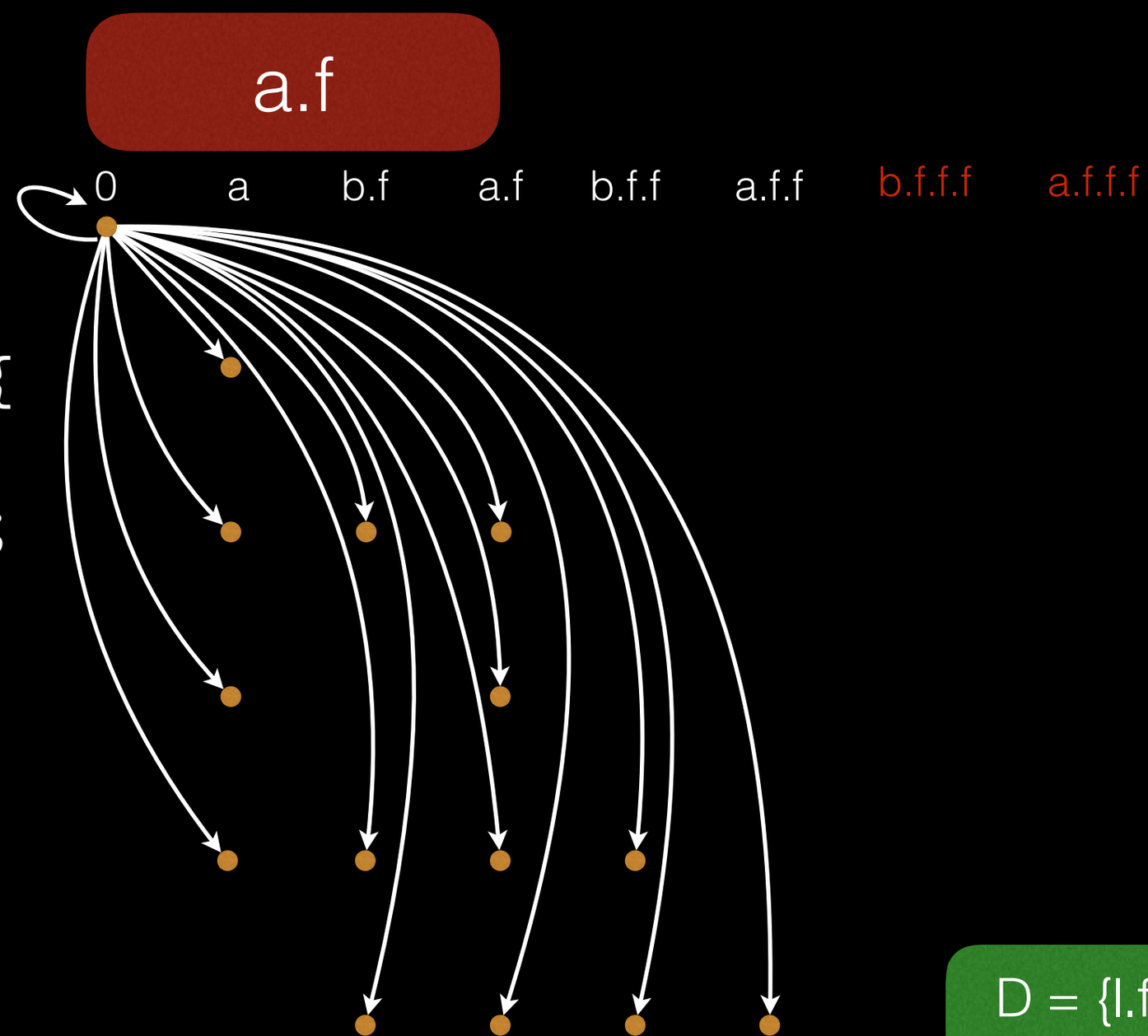
  a = b;
}

sink(d);
```



$D = \{l.f_1.f_2.f_3. \ldots .f_n\}$
$l \in$ Locals, $f_i \in$ fields
$0 \leq n \leq k$

k-Limiting

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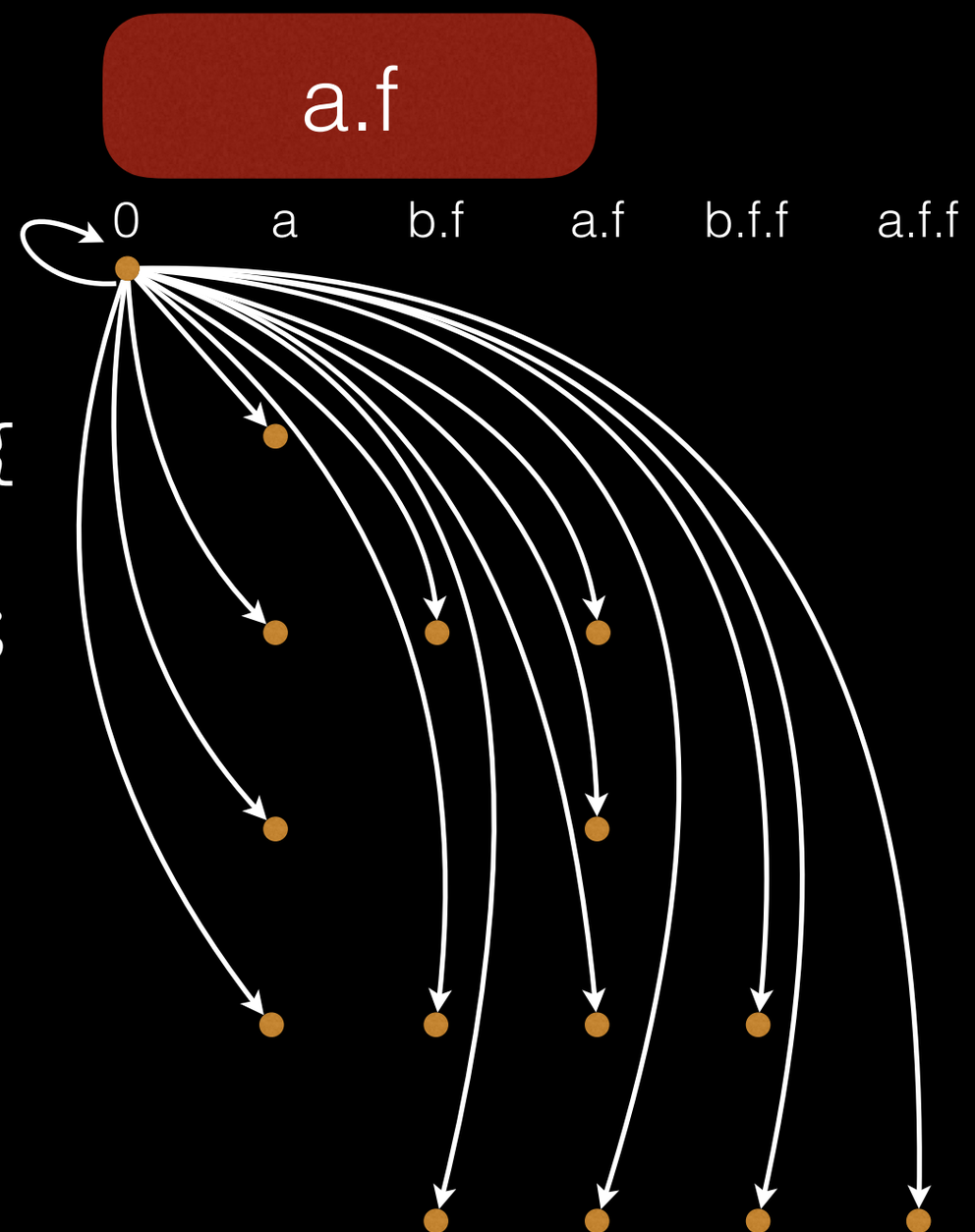


unsound domain
beyond *k* => imprecise

k = 2

$D = \{l.f_1.f_2.f_3. \ldots .f_n\}$
$l \in$ Locals, $f_i \in$ fields
$0 \leq n \leq k$

k-Limiting

```
a = source();

b = new DS();

c = new DS();

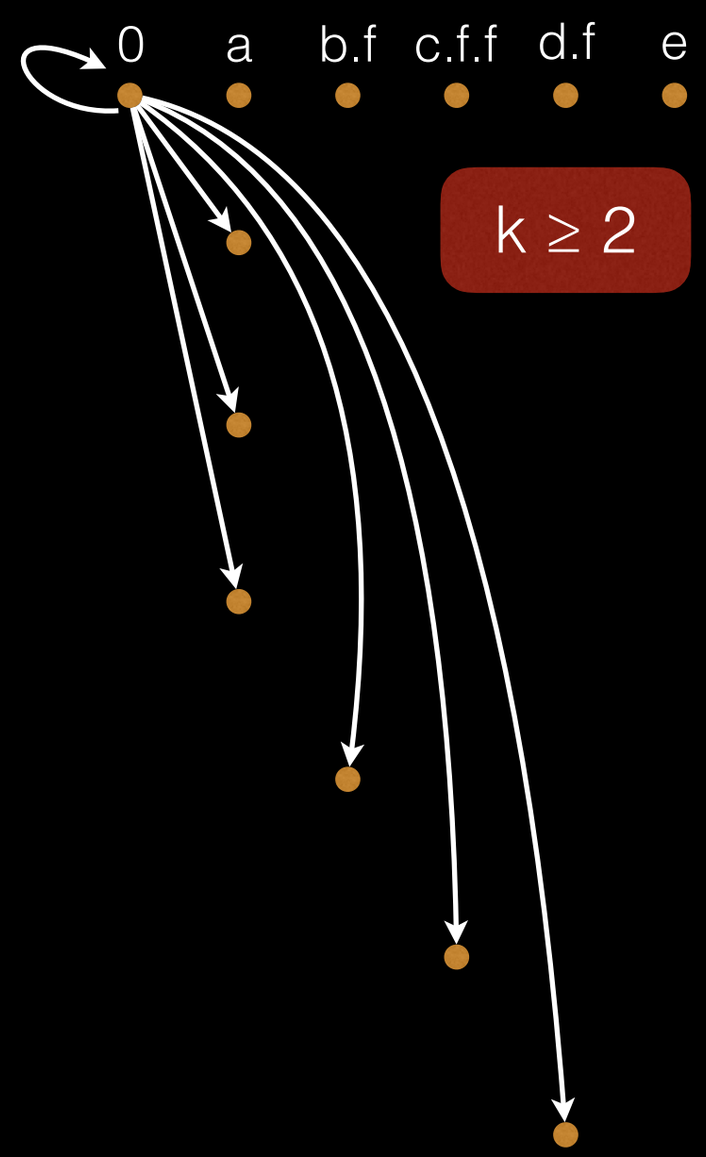
b.f = a;

c.f = b;

d = c.f;

e = d.g;

sink(e);
```



k-Limiting

```
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c = new DS();

b.f = a;

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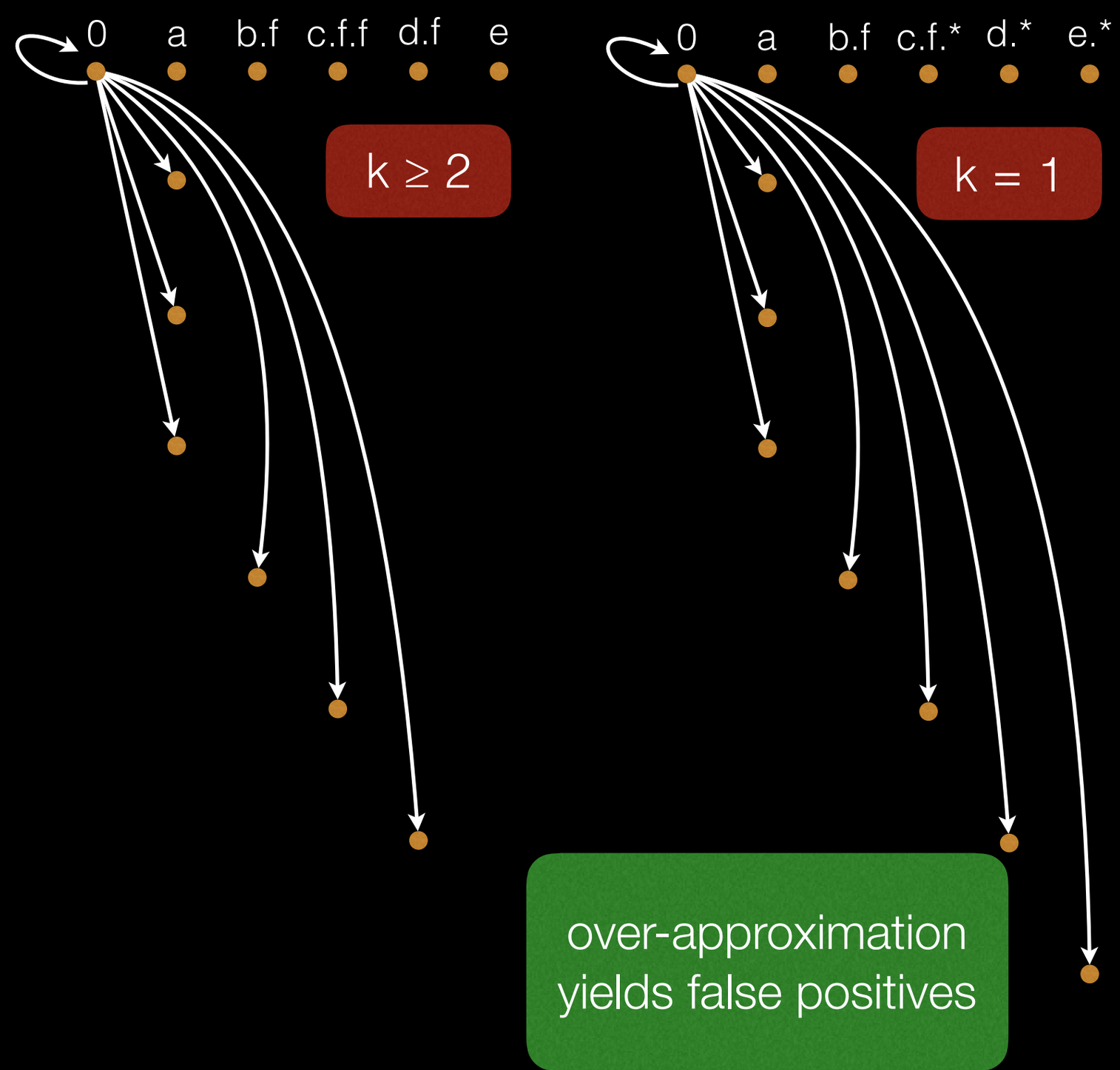


Tidbits

- Flow Sensitivity?
- Context Sensitivity?

Tidbits

- Flow Sensitivity?
- Context Sensitivity?

Method Summaries

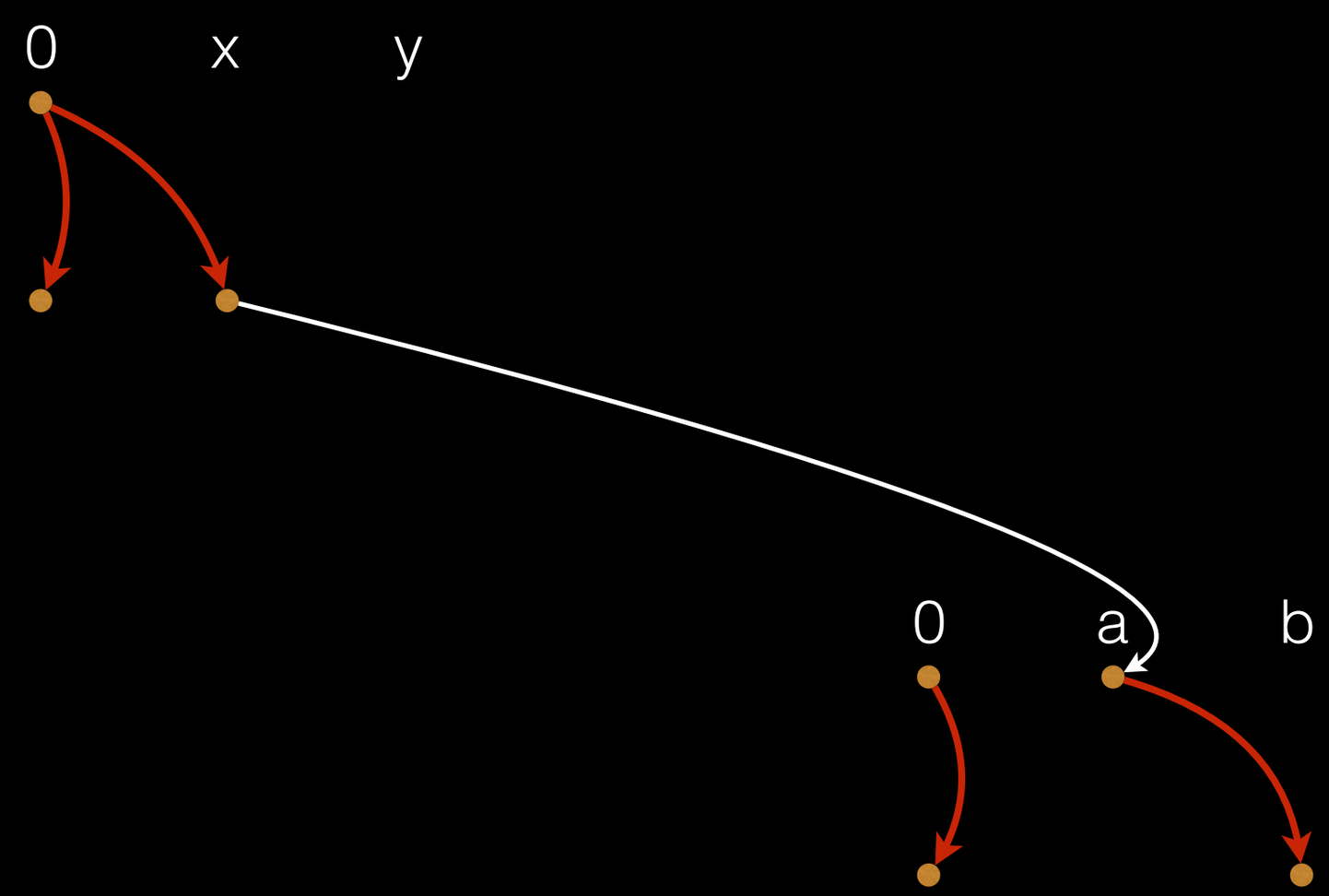
Context Sensitivity

```
...

call1();

...

call2();
```



Context Sensitivity

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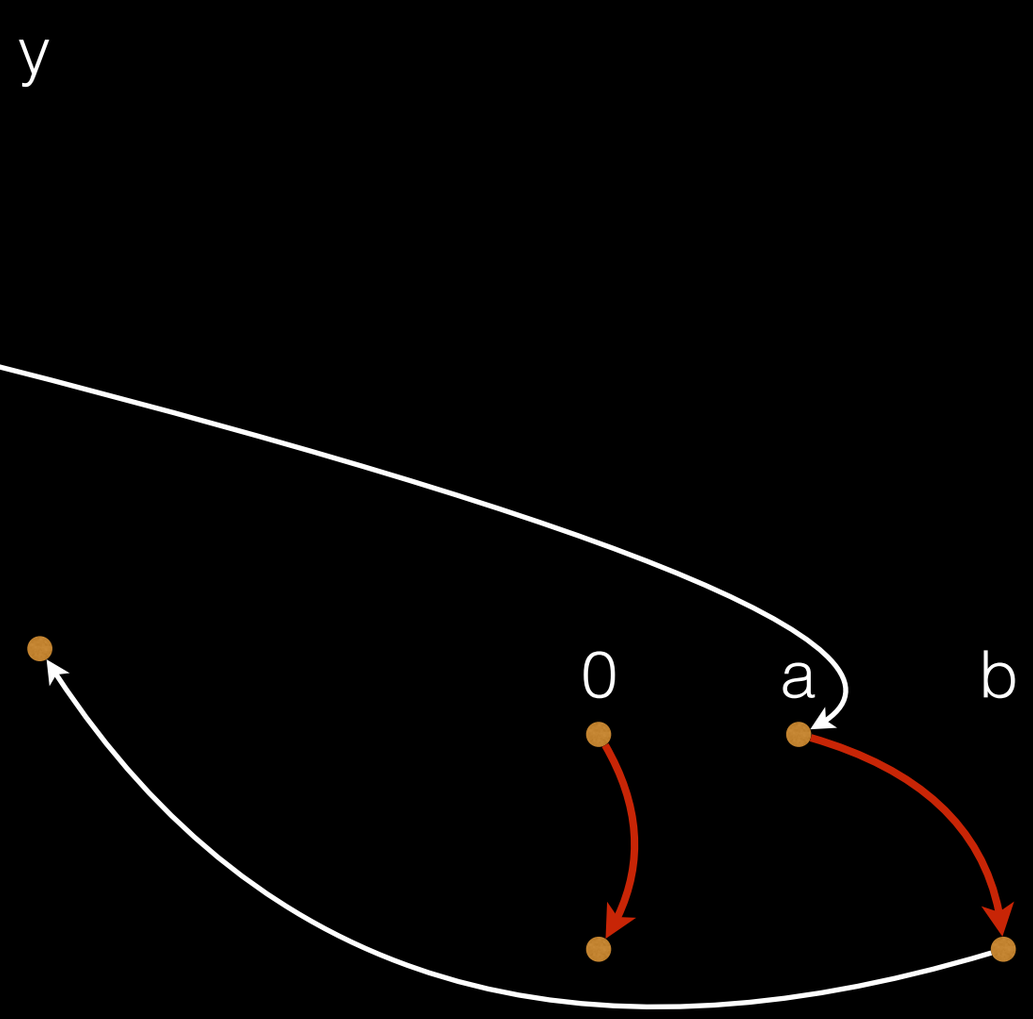
call1();

...

call2();
```



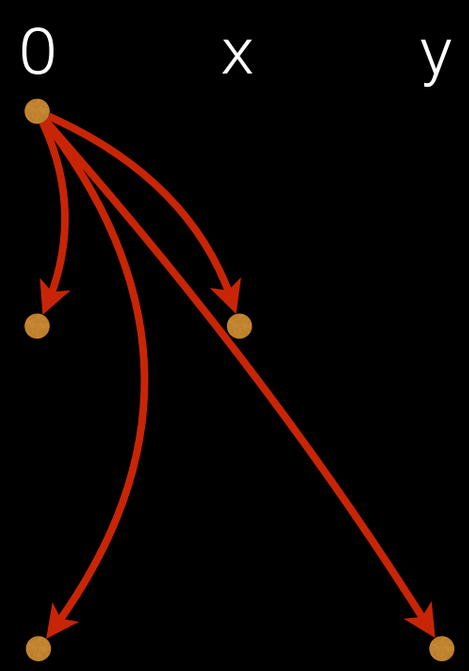
Context Sensitivity

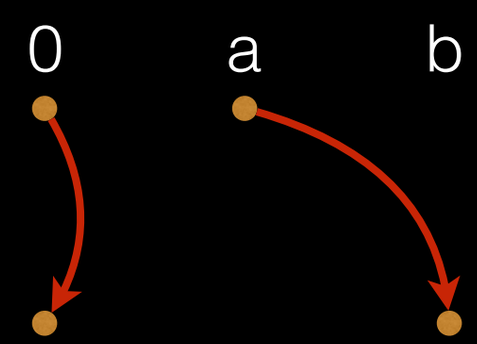
```
...

call1();

...

call2();
```





Context Sensitivity

```
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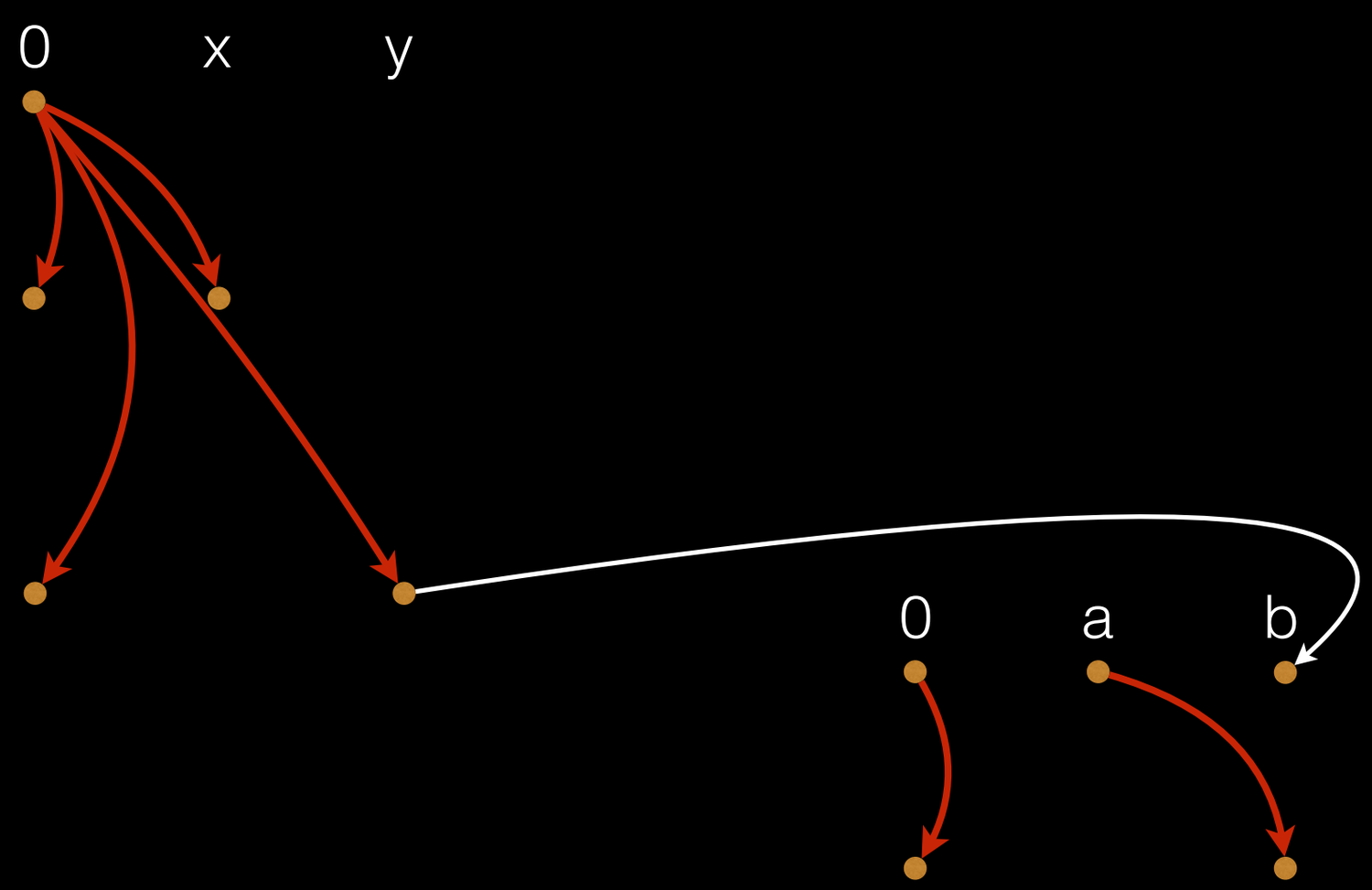
call2();
```



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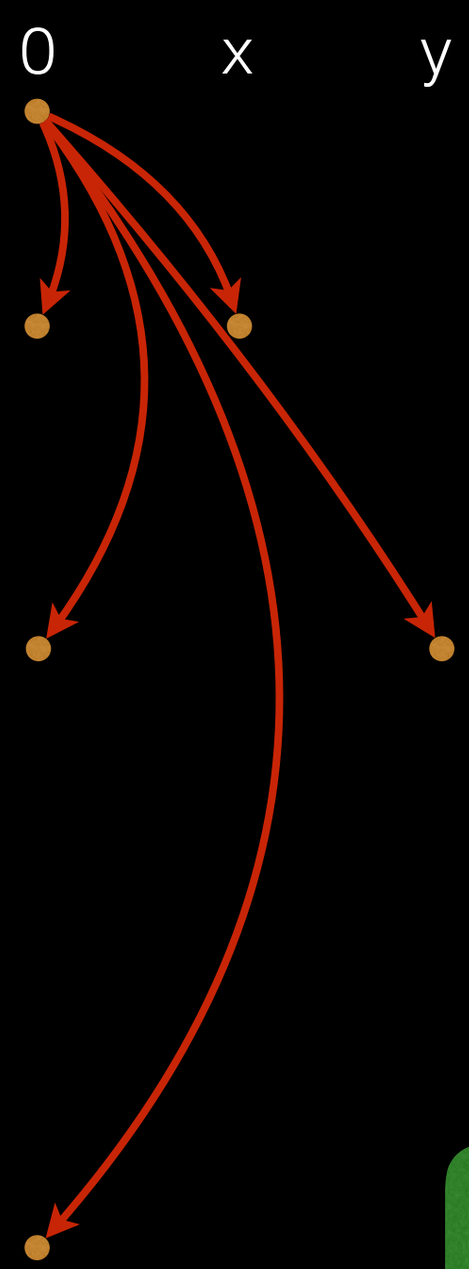
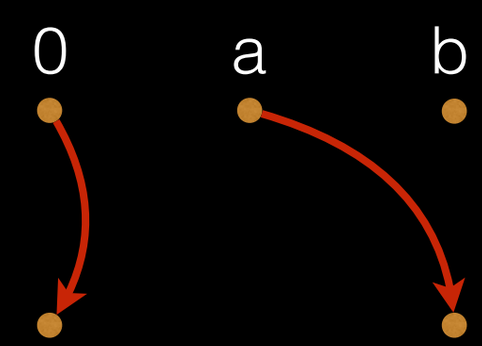




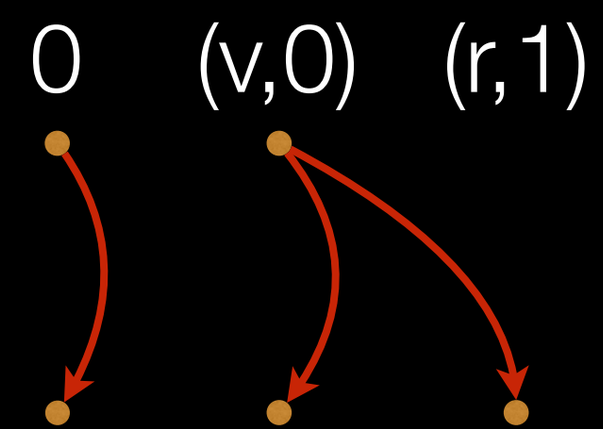
same summary
different contexts => different results

Tidbits

- Flow Sensitivity
- Context Sensitivity
- Large Domains => performance problems

Large Domains

```
r = v + 1
```

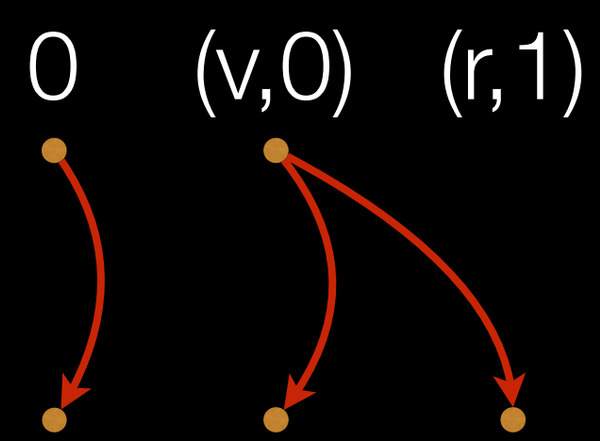


In any context, if *v* is 0 before the call, then it is true that *r* is 1 after the call

Large Domains

```
main() {
 x = inc(1);
 y = inc(x);
 z = inc(y);
 print(z);
}
```

```
inc(v) {
 r = v + 1;
 return r;
}
```



Large Domains

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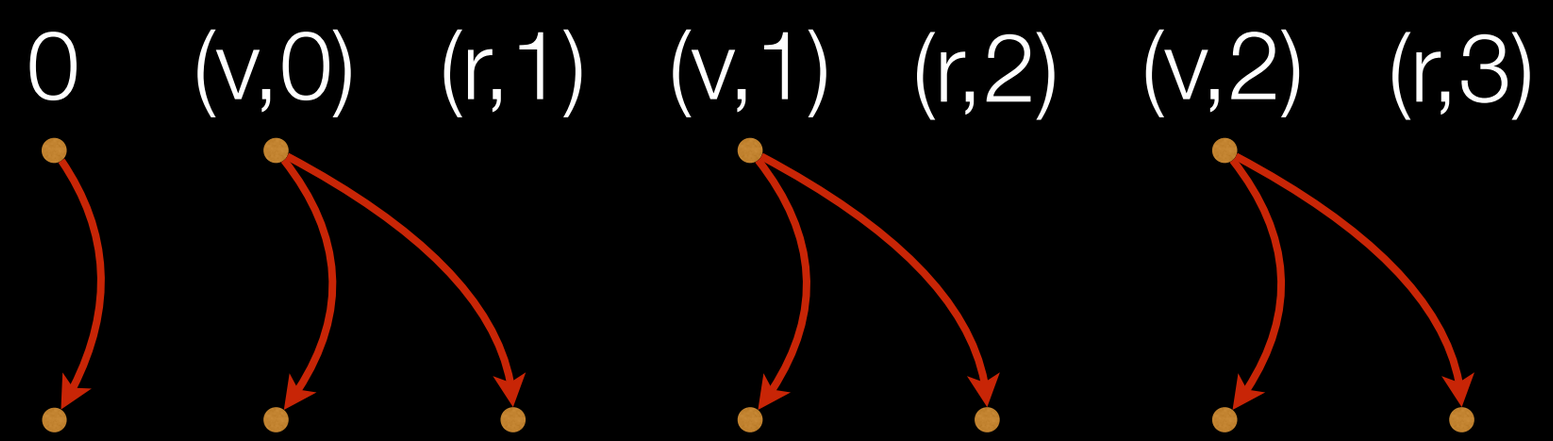

Large Domains

```
main() {
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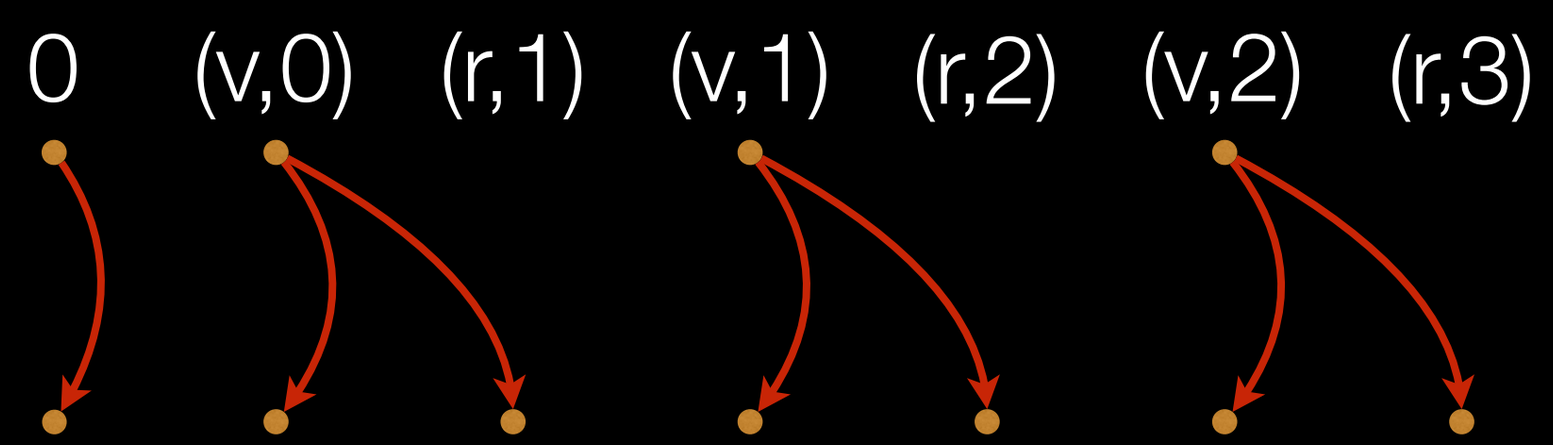
Solution: IDE instead of IFDS



Recap

- Interprocedural Finite Distributive Subset
- Flow Functions
- Taint Analysis Example
- On-the-fly ESG
- Tidbits: field-sensitivity, context-sensitivity, large domains

On Thursday

- Proposal presentations
- Solving Assignments 1 and 2 in class